CHAPTER 3

FACILITY GROUND SYSTEM FOR NEW C4ISR FACILITIES

3-1. Ground system

A facility ground system is typically comprised of four major subsystems. These are the earth electrode subsystem, the fault protection subsystem, the lightning protection subsystem, and the signal reference subsystems.

a. Earth electrode subsystem. Earth grounding is defined as the process by which an electrical connection is made to the earth. The earth electrode subsystem is that network of interconnected rods, wires, pipes, or other configuration of metals, which establishes electrical contact between the elements of the facility and the earth. The extensions into the building are used as the principal ground point for connection to equipment ground subsystems serving the facility. Ground reference is established by electrodes in the earth at the site or installation. This system should achieve the following objectives.

(1) Provide a path to earth for the discharge of lightning strokes in a manner that protects the structure, its occupants, and the equipment inside.

(2) Restrict the step-and-touch potential gradient in areas accessible to persons to a level below the hazardous threshold even under lightning discharge or power fault conditions.

(3) Assist in the control of noise in signal and control circuits by minimizing voltage differentials between the signal reference subsystems of separate facilities.

b. Fault protection subsystem. The fault protection subsystem ensures that personnel are protected from shock hazard and equipment is protected from damage or destruction resulting from faults that may develop in the electrical system. It includes deliberately engineered grounding conductors (green wires), which are provided throughout the power distribution system to afford electrical paths of sufficient capacity, so that protective devices such as fuses and circuit breakers installed in the phase or hot leads can operate promptly. If at all possible the equipment fault protection conductors should be physically separate from signal reference grounds except at the earth electrode subsystem. The equipment fault protection subsystem provides grounding of conduits for signal conductors and all other structural metallic elements as well as the cabinets or racks of equipment. In the event of transformer failure (e.g., disconnect between neutral and ground or line to ground faults) or any failure between the service conductor(s) and grounded objects in the facility, the earth electrode subsystem becomes a part of the return path for the fault current. A low resistance assists in fault clearance; however, it does not guarantee complete personnel protection against hazardous voltage gradients, which are developed in the soil during high current faults. Adequate protection generally requires the use of ground grids or meshes designed to distribute the flow of current over an area large enough to reduce the voltage gradients to safe levels. The neutral conductor at the distribution transformer must therefore be connected to the earth electrode subsystem to ensure that a low resistance is attained for the return path.

c. Lightning protection subsystem. The lightning protection subsystem provides a non-destructive path to ground for lightning energy contacting or induced in facility structures. To effectively protect a building, mast, tower, or similar self-supporting objects from lightning damage, an air terminal (lightning rod) of adequate mechanical strength and electrical conductivity to withstand the stroke impingement must he provided. An air terminal will intercept the discharge to keep it from penetrating the non-conductive outer coverings of the structure, and prevent it from passing through devices likely to be damaged or destroyed. A low-impedance path from the air terminal to earth must also be provided. These requirements are met by either an integral system of air terminals, roof conductors, and down conductors securely interconnected to provide the shortest practicable path to earth; or a separately mounted shielding system, such as a metal mast or wires (which act as air terminals) and down conductors to the earth electrode subsystem.

d. Signal reference subsystem. The signal reference subsystem establishes a common reference for communications equipment, thereby also minimizing voltage differences between equipment. This in turn reduces the current flow between equipment and also minimizes or eliminates noise voltages on signal paths or circuits. Within a piece of equipment, the signal reference subsystem may be a bus bar or conductor that serves as a reference for some or all of the signal circuits in the equipment. Between equipment, the signal reference subsystem will be a network consisting of a number of interconnected conductors. Whether serving a collection of circuits within a single piece of equipment or serving several pieces of equipment within a facility, the signal reference network will in the vast majority of cases be a multiple point/equipotential plane. However, in some cases, the signal reference subsystem can be a single point depending on the equipment design, the facility, and the frequencies involved.

e. Interfaces among the subsystems. The earth electrode subsystem provides the main grounding connection to the earth for the facility, the associated equipment, and the personnel protection requirements. This system interfaces with all the other grounding systems in that it provides the ultimate earth ground, ensuring the other systems provide the protection they were designed for.

3-2. Earth electrode subsystem

The earth electrode subsystem establishes the electrical connection between the facility and earth. This connection is necessary for lightning protection, useful in power fault protection, and in the minimization of noise. The system should be tailored to reflect the characteristics of the site and the requirements of the facility. It must be properly installed and steps must be taken to assure that it continues to provide a low resistance connection throughout the life of the structure.

a. Typical configurations. Typical configurations of an earth electrode subsystem may consist of the following.

(1) A system of buried, driven rods interconnected with bare wire that normally form a ring around the building; or

(2) Metallic pipe systems, i.e., water, gas, fuel, etc., that have no insulation joints (metallic pipe systems shall not be used as the sole earth electrode subsystem); or

(3) A ground plane of horizontal buried wires.

b. Design. To achieve the desired objectives of the earth ground system, design of the system to be installed is of utmost importance. For an acceptable system the following steps must be followed.

(1) Perform a site survey to determine the electrical and physical properties of the site,

(2) Design an earth electrode subsystem appropriate for the site,

(3) Install the subsystem in accordance with the recommended procedures, and

(4) Measure the earth resistance of the subsystem to verify that it meets the recommended goals or design specifications.

c. Soil resistivity. As the first step of the site survey, measure the resistivity of the soil at several points over the area of the planned facility. For even the smallest facility, the effective facility area in so far as the electrode subsystem is concerned is assumed to be at least 15 meters by 15 meters (50 feet by 50 feet). For larger facilities, the facility areas are assumed to extend at least 6 meters (20 feet) beyond the basic building or structural outline, i.e., the ground floor plan, substation grid, tower footing, transformer housing, etc. It is necessary that the soil resistivity be known over the area encircled or covered by the earth electrode subsystem. It is not always possible to ascertain with a high degree of certainty the exact type of soil present at a given site. Soil is typically rather non-homogeneous; many types will be encountered at most locations. Even with the aid of borings and test samples the resistivity estimate can easily be off by two or three orders of magnitude. When temperature and moisture variations are added to the soil type variations, it is evident that estimates based on standard values are not sufficiently accurate for design purposes. The only way to accurately determine the resistivity of the soil at a specific location is to measure it. The most commonly used field methods for determining soil resistivity employ the technique of injecting a known current into a given volume of soil, measuring the voltage drop produced by the current passing through the soil, and then determining the resistivity using standard equations.

(1) The one electrode method involves driving a round electrode in the earth and then inducing a current into it. In uniform earth, injected current flows radially from the hemispherical electrode. Equipotential surfaces are established concentric with the electrode and perpendicular to the radial directions of current flow. As the current flows from the hemisphere, the current density decreases with distance from the electrode because the areas of successive shells become larger and larger. The current density within the earth, at given distances from the center of the electrode, is then calculated. The electric field strength is then calculated, which allows the resistance and subsequently the resistivity of the earth to be calculated. Approximate values of earth resistivity are given in table 3-1.

Table 3-1. Approximate soil resistivity

Type of Soil	**Resistivity**		
	Ohm-m	Ohm-cm	Ohm-ft
Wet Organic	10	10^3	33
Moist	10^2	10^4	330
Dry	10^3	10^5	3300
Bed Rock	10^4	10^6	33000

(2) In the four-terminal method developed by the U.S. Bureau of Standards, four electrodes are inserted into the soil in a straight line with equal spacings. A known current is injected into the soil through the end electrodes and the voltage drop between the two inside electrodes is measured. Connection is made to the electrodes by insulated conductors. The current is introduced into one of the outermost spheres and flows out of the earth through the other outermost sphere. The voltage from the left hand to the right hand inner sphere can be viewed as resulting from a current flowing to infinity and

another returning from infinity. The resistance and subsequently the earth resistivity can then be calculated.

d. Geological considerations. Identify the significant geological features of the site. Specifically, attempt to establish:

(1) The distribution of major soil types to include the locations of sand and gravel deposits

(2) Major rock formations

(3) The presence of water sources to include underground streams

(4) The depth of the water table

(5) Utilize test borings, on site inspections, studies of local maps, and interviews with local construction companies, well drillers, and other local personnel to obtain the desired information.

(6) Evaluate the information provided by these sources for indications of particularly troublesome (or particularly helpful) characteristics that may influence the design or installation of the earth electrode subsystem of the facility.

e. Physical features. Locate and identify those other physical features that will influence the general placement of the earth electrode subsystem, the location of test and access points, physical protection requirements, and the cost of materials and installation. For example, indicate on the general site plan the planned physical layout of the building or structure, locations of paved roads and parking lots, drainage (both natural and man-made), and the location of buried metal objects such as pipes and tanks.

f. Local climate. Review local climatic conditions and determine the annual amount and seasonal distribution of rainfall, the relative incidence of lightning, and the depth of freezing (frost line) typical of the area. Obtain the rainfall and frost line information from the local weather service and project the relative lightning incidence from isokeraunic maps. Record the data and make it a part of the facility files for the site. Immediately, however, use this information to aid in the design of the earth electrode subsystem for the facility to be constructed at the site.

g. Design procedure. The detailed design process involves discrete steps that ensure the system will perform the intended function.

(*1)* Determine what type of earth electrode subsystem is most appropriate for the facility. The directed configuration is a ring ground. If this configuration cannot be employed, alternate configurations meeting the requirements must be considered.

(2) Establish the primary functional requirements to be met by the earth electrode subsystem.

(a) For a facility located in an area of high lightning incidence or a high degree of exposure to lightning, or both, the earth electrode subsystem must safely dissipate the lightning energy without melting conductors or overheating the soil. Also, the subsystem must minimize step voltages in areas where personnel are present.

(b) If the antenna counterpoise must serve as an earth electrode subsystem, it must have low RF impedance properties.

(c) At fixed facilities, the earth electrode subsystem should exhibit a resistance to earth of 10 ohms or less. If 10 ohms is not economically feasible by the ring ground, alternate methods should be considered

(3) The conditions of the site and its location must be considered in the design process.

(a) Determine if the soil resistivity is low (< 5000 ohm-cm), average (5000 to 20,000 ohm-cm), or high (> 20,000 ohm-cm). The higher the soil resistivity, the more complex (and expensive) will be the electrode subsystem necessary to achieve 10 ohms resistance.

(b) Consideration must be given to the water table at the site. Factors to consider include its location in relation to the surface and whether or not it is subject to large seasonal variations. Design the earth electrode subsystem so that it makes and maintains contact with soil that stays damp or moist year round if at all possible. Penetration of the permanent water table is highly desirable.

(c) The depth of the frost line even in the coldest periods must be determined. The resistivity of soil rises greatly as the soil temperature drops below 32° F. Thus for maximum stability of electrode resistance, the subsystem should penetrate far enough into the soil so that contact is always maintained with unfrozen soil. In permafrost, fault protection must be provided through the use of metallic returns accompanying the power conductors to insure the existence of a return path to the transformer or generator. Personnel protection in permafrost requires an even greater emphasis on the bonding of all metal objects subject to human contact and to the power system neutral. Because of the high resistance of permafrost, stray earth currents can be expected to be minimal with consequently reduced concern with inter-facility power frequency noise problems.

(d) Major rock formations near the surface large enough to influence the design and layout of the earth electrode subsystem must be considered. In regions of shallow bedrock, vertical ground rods may not be usable and horizontal grids, wires, or plates must be used. Large rock outcropping or subsurface boulders may force the alternate routing of conductors or the placement of rods. There is no need to incur the expense of drilling holes in rock to insert rods or lay wires because the resistivity of rock is so high that generally the rods or wires would be ineffective.

(4) The design of the earth electrode subsystem must be such that it will not be materially influenced by the weather shielding effects of parapets and overhangs. Lightning down conductor placement and routing will frequently be influenced by architectural considerations. Design the earth electrode subsystem to accommodate such considerations by providing convenient connection points near the down conductors. Route the interconnecting cable of the earth electrode subsystem near down conductors to avoid long extensions between the down conductor and the effective grounding point. Configure the earth electrode subsystem such that convenient connections are possible between the earth electrode subsystem and grounding conductors of the power and signal ground systems inside the facility.

(5) Preferably locate ground subsystem conductors under sodded areas or those otherwise covered with vegetation. Locate conductors to take maximum advantage of the wetting effects of runoff or drainage water from the roof, parking lots, etc. Try to avoid placing major portions of this earth electrode subsystem under extensive paved areas such as roads and parking lots.

(6) Considering the relative advantages and disadvantages given in table 3-2, choose a basic type of electrode most appropriate for meeting the functional requirements of the facility at the site under construction.

Table 3-2. Relative advantages and disadvantages of the principal types of earth electrodes

Type	Advantages	Disadvantages
Ring Ground	Straightforward design. Easy to install (particularly around an existing facility). Hardware readily available. Can be extended to reach water table.	Not useful where large rock formations are near surface.
Horizontal Bare Wires (Radials)	Can achieve low resistance where rock formations prevent use of vertical rods. Low impulse impedance. Good RF counterpoise when laid in star pattern.	Subject to resistance fluctuations with soil drying.
Horizontal Grid (Bare Wire)	Minimum surface potential gradient. Straightforward installation if done before construction. Can achieve low resistance contact in areas where rock formations prevent use of vertical rods. Can be combined with vertical rods to stabilize resistance fluctuations.	Subject to resistance fluctuations with soil drying if vertical rods not used.
Vertical Rods	Straightforward design. Easiest to install (particularly around an existing facility). Hardware readily available. Can be extended to reach water table.	High impulse impedance. Not useful where large rock formations are near surface. Step voltage on earth surface can be excessive under high fault currents or during direct lightning strike.
Plates	Can achieve low resistance contact in limited area.	Most difficult to install.
Incidental Electrodes (utility pipes, building foundations, buried tanks)	Can exhibit very low resistance.	Little or no control over future alterations. Must be employed with other made electrodes.

(7) Estimate the relative costs to meet the objectives with the different types of configurations. Include the cost of materials, installation costs, and relative maintenance and upgrading costs.

(8) Once the most appropriate configuration is chosen for the facility, calculate the resistance to earth for the configuration. If the calculated resistance meets the design goal (or requirement), complete the design to include all necessary interconnections.

(9) Non-ideal sites will frequently be encountered and will require an alternate configuration from the standard ring ground system. For example, large rock formations may be present which prevent the uniform placement of ground rods around the site; bed rock may be relatively near the surface; the water level may drop to several feet below grade; the soil resistivity may be very high; or architectural and landscape requirements may preclude locating ground rods at particular points. In such cases, modify the electrode configuration to conform to the constraints while achieving the desired resistance. Typical suggested alternatives are:

(a) Change number of ground rods.

(b) Use longer ground rods. Rods longer than 10 feet may be used in high resistivity soil in place of a larger number of 10-foot rods. Where the ground water table is greater than 10 feet below the surface at any season of the year or where the frost line is greater than 10 feet, use the longer rods to maintain contact with the permanently moist, unfrozen soil.

(c) Use horizontal wires or grids instead of vertical rods. Where bedrock or other obstacles prevent the effective use of vertical rods, horizontal wires, grids, or radials should be used.

(d) Lower the soil resistivity through chemical enhancement (salting). Where the above alternatives are not possible or are not cost effective, chemical enhancement is frequently the only choice left.

h. Minimum design requirements. The design of each ground system is unique to the particular facility and the conditions present. However, a minimum set of requirements shall be considered for each facility.

(1) At each facility supplied by electric power, at least one ground rod should be installed near the service disconnecting means and bonded to the earth electrode subsystem. If the transformer is located on the site, a bare 1/0 AWG wire or cable should interconnect the ground rod at the transformer with the earth electrode subsystem at the first service disconnect for lightning protection purposes.

(2) For lightning protection purposes, all facilities large or small or located in areas of low or high lightning incidence will require an earth electrode subsystem. Facilities having structural extensions or equipment protrusions (such as antenna elements or towers) extending above the surrounding terrain should have a continuous earth electrode subsystem enclosing each facility or should have individual earth electrode subsystems connected together.

(3) Most installations will require many interconnected ground rods. The configuration shown in figure 3-1 is adequate for most facilities. (The number of ground rods actually required at a given location will be determined by the resistivity of the soil and the configuration of the installation.) Three-meter (10-foot) ground rods installed at 20-foot intervals around the perimeter of the structure provide good utilization of the effective radius of the rod while providing several points of contact with the earth. If longer rods are required to reach the water level, to make contact with lower resistivity soils, or to penetrate below the frost line, greater spacings may be employed. The nominal spacing between rods should be between one and two times the length of the rod; however, it is necessary for each lightning down conductor to be connected to its own dedicated ground rod, so spacing should be limited to not more than 50 feet in order to conform to lightning protection requirements.

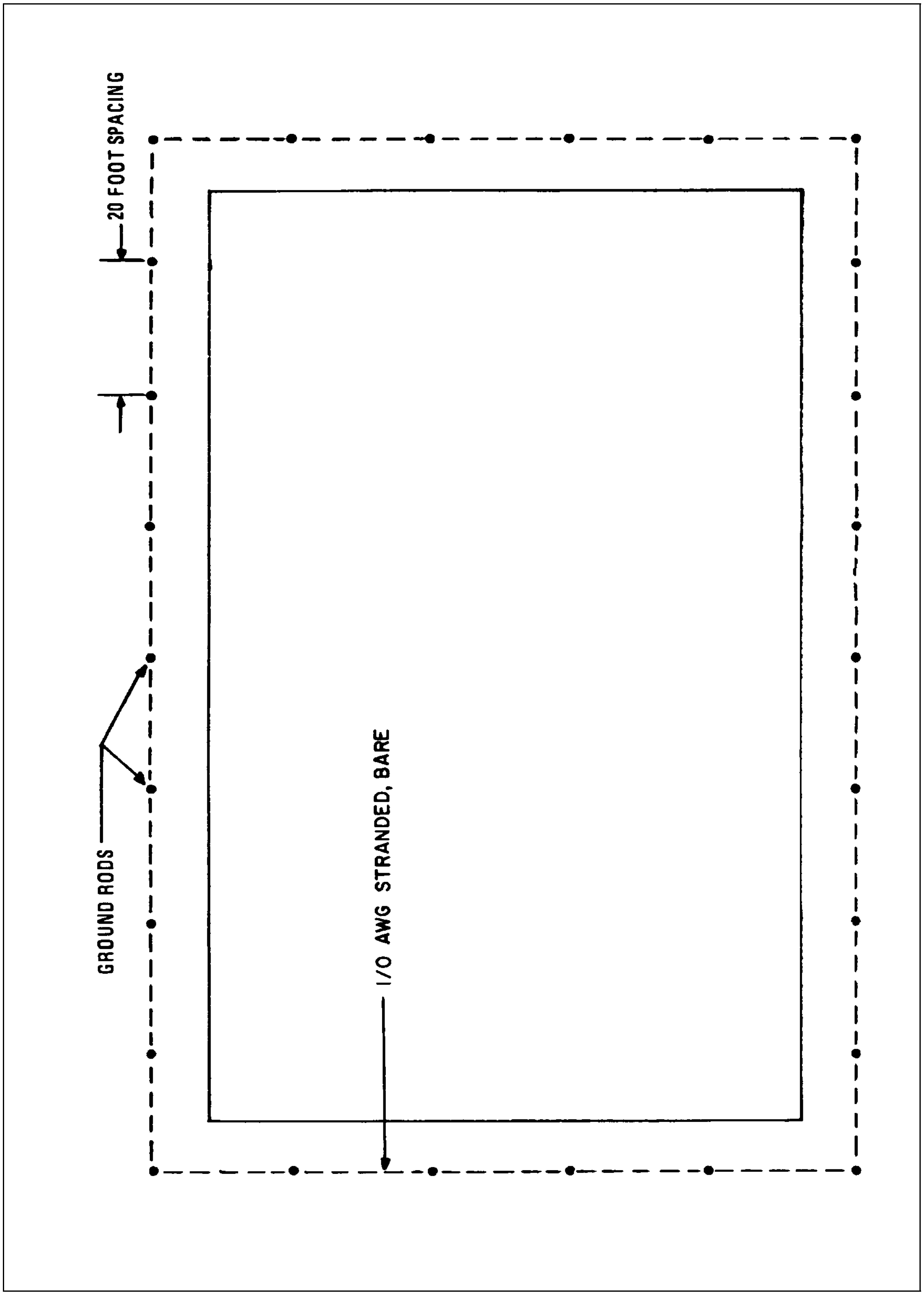

Figure 3-1. Earth electrode subsystem configuration for rectangular shaped facility

(4) The rods and interconnecting cable comprising the earth electrode subsystem should be positioned 0.6 to 1.8 meters (2 to 6 feet) outside the drip line of the building or structure to insure that rain, snow, and other precipitation wets the earth around the rods.

(5) For facilities that do not conform to a rectangular or square configuration, lay out the rod field to generally follow the perimeter of the structure. See figure 3-2 for an example.

(6) When two or more structures or facilities are located in the same general area (less than 200 feet) and are electrically interconnected with signal, control, and monitor circuits, either provide a common earth electrode subsystem, or interconnect the separate earth electrode subsystems with two buried bare cables. See figure 3-3 for an example. A common example of an installation where two separate structures are involved is a radar or communications site where the equipment shelter is adjacent to the antenna tower. Signal cables (both coaxial and waveguide), control cables, and power lines typically run between the tower and the shelter. The tower, being taller than the shelter, is more susceptible to lightning strikes. To minimize voltage differentials between the two structures, the facilities should effectively share a common earth electrode subsystem. Separate structures spaced closer than 6 meters (20 feet) should have a common earth electrode subsystem installed that encircles both facilities. Structures or facilities having no interconnecting cables and separated by a distance greater than 60 meters (200 feet) generally do not require their earth electrode subsystems be interconnected.

(7) There may be a number of incidental, buried, metallic structures in the vicinity of the earth electrode subsystem. These structures should be connected to the subsystem to reduce the danger of potential differences during lightning or fault protection; their connection will also reduce the resistance to the earth of the electrode subsystem. Such additions to the earth electrode subsystem should include the rebar in concrete footings, buried tanks and pipes.

(8) To minimize resistance variations caused by surface drying of the soil and by the freezing of the soil during winter and to minimize the possibility of mechanical damage to ground rods, connections, and interconnecting cables, the tops of ground rods should be at least 0.3 meters (1.0 foot) below grade level. Bury the bare 1/0 AWG interconnecting cable at least 0.45 meters (1.5 feet) below grade level.

(9) If the subsystem is installed after foundations are poured, cables are installed, utility pipes installed, etc., make proper provisions for performing the needed interconnections between the water system, lightning down conductors, structural steel, buried lines and cables, and the electrodes.

(10) Access to the earth electrode subsystem should be provided through the installation of one or more grounding wells at each site. Two acceptable types of grounding wells are illustrated in figure 3-4. Either clay pipe or poured concrete may be used. Removable access covers must be provided. In very large structures, particularly those in which grounding grids are installed underneath, the grounding well or wells may be located inside the building in an accessible location. More than one grounding well may be necessary depending upon the size of the facility, the extent of the electrode subsystem, and the degree of accessibility to the electrodes deemed desirable. Locate at least one of the ground wells in an area with access to open soil so that resistance checks of the earth electrode subsystem can be made once the building is in use.

i. Typical components. Earth electrode subsystems can be divided into two general types, the most preferable being a ring ground with 10-foot (3-meter) minimum length ground rods every 15 feet (4.5 meters). A second and less preferable type consists of a system of radials or grounds used when soil is rocky or has extremely high resistivity. At sites where soil resistivity varies from high to very high and frequent electrical storms are common, a combination of the two is recommended, i.e., a ring ground

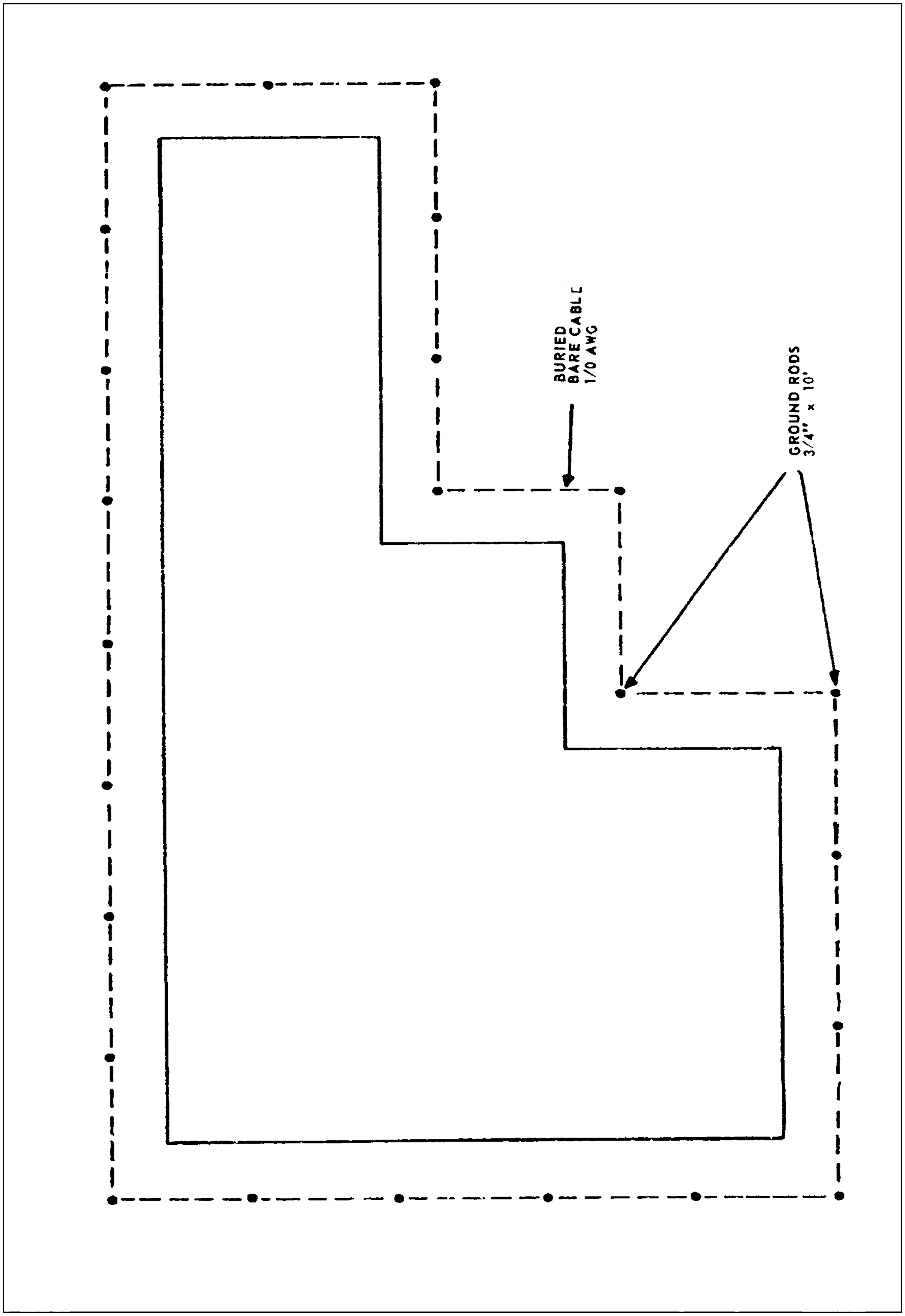

Figure 3-2. Earth electrode subsystem configuration for irregular shaped facility

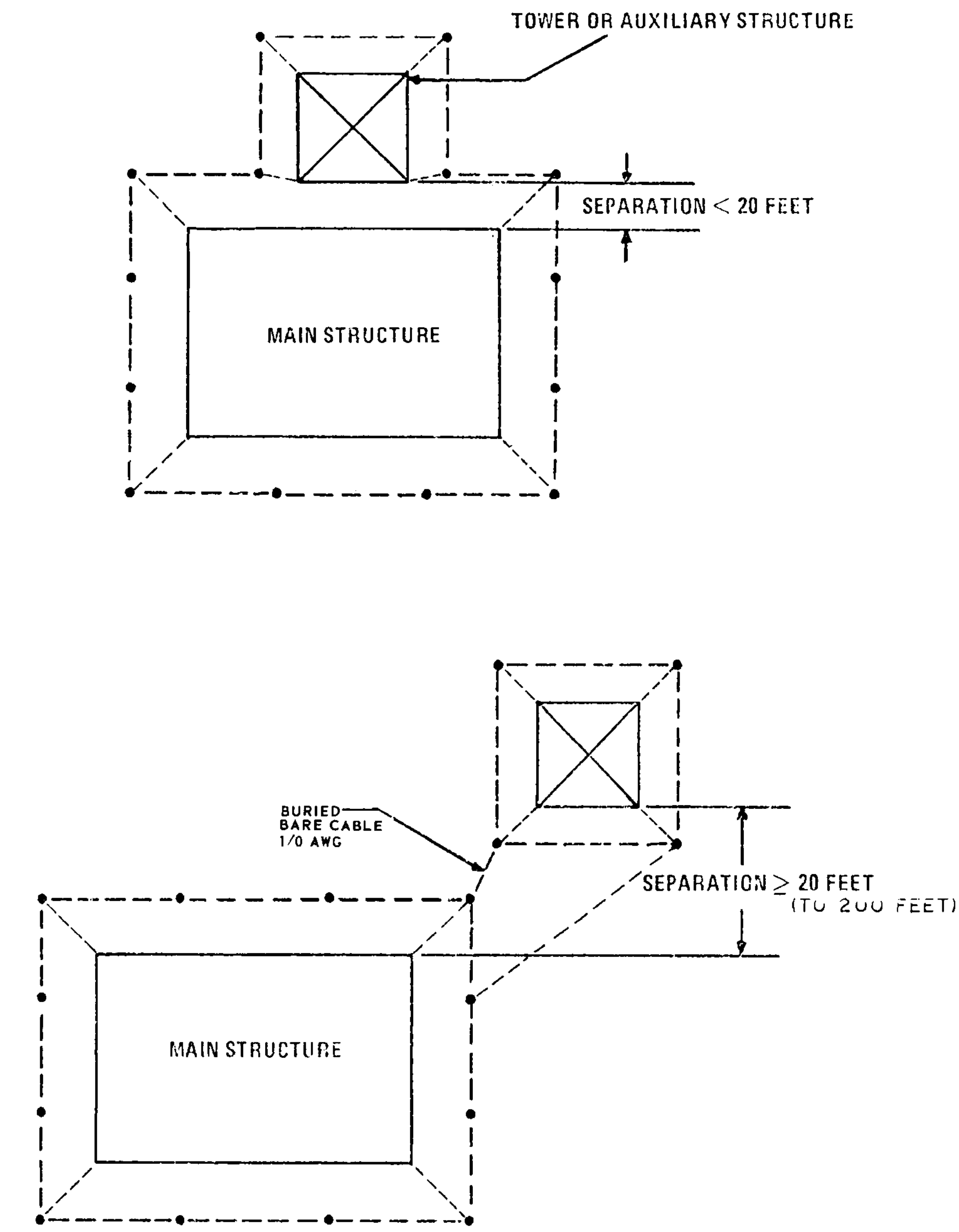

Figure 3-3. Electrode configuration for closely adjacent structures

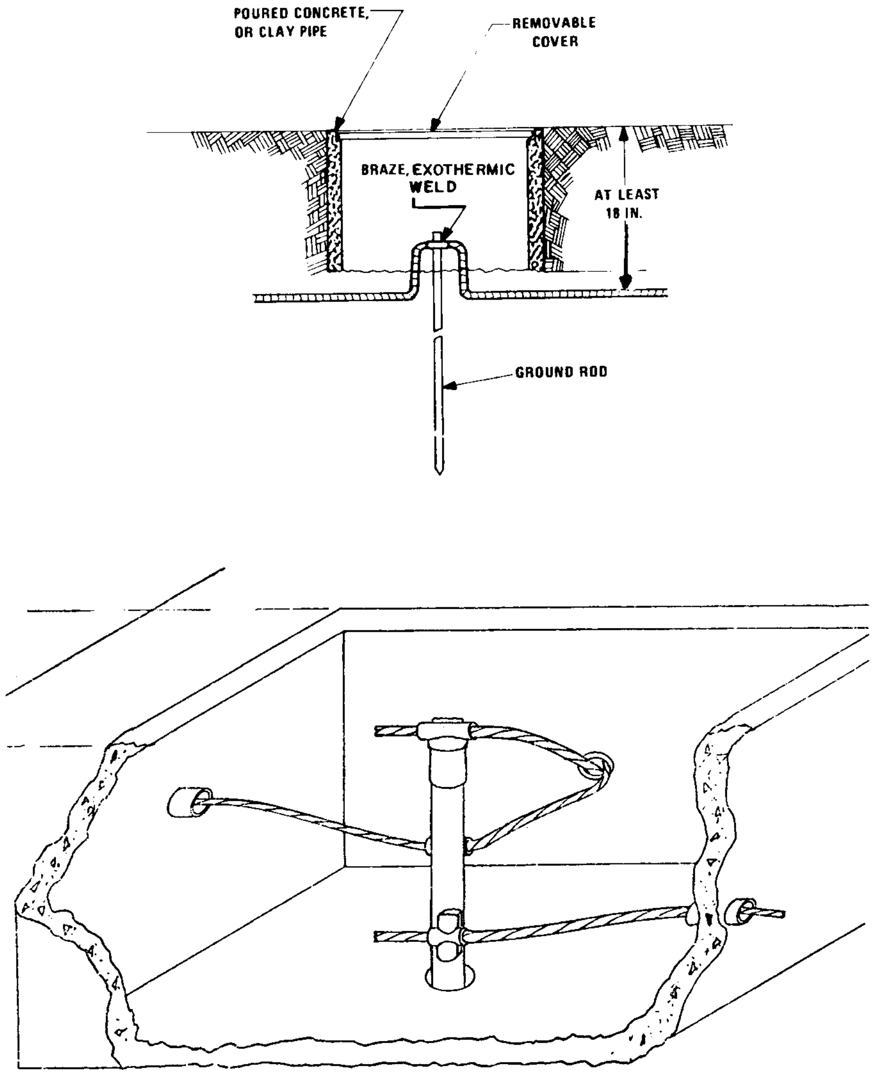

Figure 3-4. Typical grounding well installation

around the building (worst case-grid under building) extending 2 to 6 feet (0.6 to 1.8 meters) outside the drip line with radials or horizontal conductors extending to 125 feet (37.5 meters). With either system, resistance to earth and danger of arc over can be greatly reduced by bonding any large metal objects in the immediate area to the earth electrode subsystem. These include metal pipes, fuel tanks, grounded metal fences, and well casings. The advantages and disadvantages of each type of system are shown in table 3-2.

(1) Vertically driven ground rods or pipes are the most common type of made electrode. Rods or pipes are generally used where bedrock is beyond a depth of 3 meters (10 feet). Ground rods are commercially manufactured in 1.27, 1.59, 1.90 and 2.54 cm (1/2, 5/8, 3/4 and 1 inch) diameters and in lengths from 1.5 to 12 meters (5 to 40 feet). For most applications, ground rods of 1.90 cm (3/4 inch) diameter, and length of 3.0 meters (10 feet), are used. Copper-clad steel ground rods are required because the steel core provides the strength to withstand the driving force and the copper provides corrosion protection and is compatible with copper or copper-clad interconnecting cables.

(2) Where bedrock is near the surface of the earth, the use of driven rods is unpractical. In such cases, horizontal strips of metal, solid wires, or stranded cables buried 0.48 to 0.86 meters (18 to 36 inches) deep may be used effectively. With long strips, reactance increases as a factor of the length with a consequent increase in impedance. Low impedance is desirable for minimizing lightning surge voltages. Therefore, several wires, strips, or cables arranged in a star pattern, with the facility at the center, is preferable to one long length of conductor.

(3) Grid systems, consisting of copper cables buried about 15.24 cm (6 inches) in the ground and forming a network of squares, are used to provide equipotential areas throughout the facility area. Such a system usually extends over the entire area. The spacing of the conductors, subject to variation according to requirements of the installation, may normally be 0.6 to 1.2 meters (2 to 4 feet) between cables. The cables must be bonded together at each crossover. Grids are generally required only in antenna farms or substation yards and other areas where very high fault currents are likely to flow into the earth and hazardous step potentials may exist or soil conditions prohibit installation of other ground systems. Antenna counterpoise systems shall be installed in accordance with guidance requirements of the manufacturer.

(4) Rectangular or circular plate electrodes should present a minimum of 0.09 square meters (2 square feet) of surface contact with the soil. Iron or steel plates should be at least 0.64 cm (1/4 inch) thick and non-ferrous metals should be at least 0.15 cm (0.06 inches) thick. A burial depth of 1.5 to 2.4 meters (5 to 8 feet) below grade should be maintained. This system is considered very expensive for the value produced and is generally not recommended.

(5) The metal frameworks of buildings may exhibit less than 10 ohms, depending upon the size of the building, the type of footing, and particular location. Buildings that rest on steel pilings in particular may exhibit a low impedance connection to earth. For this low resistance to be used advantageously, it is necessary that framework be bonded together.

(6) Metal underground pipes have traditionally been relied upon for grounding electrodes. The resistance to earth provided by piping systems is usually quite low because of the extensive contact made with soil. Municipal water systems in particular establish contact with the soil over wide areas. For water pipes to be effective, any possible discontinuities must be bridged with bonding jumpers. The National Electrical Code (NEC) requires that any water metering equipment and service unions be bypassed with a jumper not less than that required for the grounding connector. However, stray or fault currents flowing through the piping network into the earth can present a hazard to workmen making repairs or modifications to the water system. For example, if the pipes supplying a building are disconnected from the utility system for any reason, that portion connected to the building can rise to a hazardous voltage level relative to the rest of the piping system and possibly with respect to the earth. In particular, if the resistance that is in contact with the soil near the building happens to be high, a break in the pipe at even some distance from the building may pose a hazardous condition to unsuspecting workmen. Some water

utilities are inserting non-conductive couplings in the water mains at the point of entrance to buildings to prevent such possibilities. For these reasons, the water system should not be relied upon as a safe and dependable earth electrode for a facility and should be supplemented with at least one other ground system.

(7) There may be a number of incidental, buried, metallic objects in the vicinity of the earth electrode subsystem. These objects should be connected to the system to reduce the danger of potential differences during lightning or power fault conditions: their connection will also reduce the resistance to earth of the earth electrode subsystem. Such additions to the earth electrode subsystem should include the rebar in concrete footings, buried tanks, and piping.

(8) *W*ell casing can offer a low resistance contact with the earth. In some areas, steel pipe used for casing in wells can be used as a ground electrode. Where wells are located on or near a site, the resistance to earth of the casing should be measured and, if below 10 ohms, the well casing can be considered for use as a ground electrode.

j. Installation practices. The installation of the system must be performed in conjunction with other construction activities for the facility.

(1) The schedule for installation must be such that any needed excavation, such as hole and trench digging, can be performed while other excavating, clearing, and earth moving operations associated with construction of the facility are in progress. If the subsystem is installed prior to completion of other earth moving operations, take the precautions necessary to assure that the components are not damaged or broken.

(2) All metallic lines, such as water lines, sewer lines (if metal), armored cable, etc., must be bonded to the earth electrode subsystem. Bonding jumpers of 1/0 AWG, or larger, bare copper wire are to be used for this purpose.

(3) Before covering the earth electrode subsystem with backfill dirt or otherwise rendering it inaccessible, make visual checks of all joints and connections to check mechanical integrity, to verify the absence of voids or other indications of poor bonding, and to see that all required interconnections are made.

(4) All bonds in concealed locations must be brazed or welded. Any bonds between dissimilar metals, such as between a copper wire and cast iron or steel pipe, must be thoroughly sealed against moisture to minimize corrosion. Bolted clamp connections are to be made only in manholes or in grounding wells and are to be readily accessible for verification of integrity.

(5) Drive rods only into undisturbed earth or into thoroughly tamped or compacted filled areas. Rods and cables should be placed in the backfill around foundations only after the soil has been compacted or has had adequate time to settle. Do not drive or lay rods in gravel beds which have been installed for drainage purposes unless the rods extend through such beds far enough to provide at least 1.8 to 2.4 meters (6 to 8 feet) of contact with the undisturbed earth underneath. Do not lay horizontal cables in such beds under any circumstances.

(6) Rods may be driven either by sledgehammer or with the use of power drivers. Use driving nuts to prevent damage to the driven end, particularly if two or more sections are to be joined. Deep driven rods or those driven into hard or rocky soil generally require the use of power drivers with special driving collars to prevent damage to the rod.

(7) Attach the interconnecting cable to the rods by brazing, welding, or clamping. Use bolted, clamped-type connections only if the tops of the rods are accessible through grounding wells and a periodic maintenance program is established to verify the integrity of the connection on a regular basis.

(8) As rods are installed, make a one-time resistance check of each rod once it reaches its intended depth. This subsystem should be visually inspected every 2 months, mechanically inspected every 12 months, and electrically tested every 24 months, per InterNational Electrical Testing Association's (NETA) guidelines. See text for specific recommendations. Use the fall of potential method outlined in MIL-HDBK-419A, Grounding, Bonding, and Shielding for Electronic Equipment and Facilities. In this way a continuous check is made of the electrode design. If the measured resistance of the rods is less than the calculated resistance, the use of fewer rods may be acceptable as long as the minimum number required for terminating lightning down conductors is installed. On the other hand, if the measured resistance of the rods is greater than calculated, additional rods or longer rods should be installed during the construction stage rather than waiting until the facility is completed to add additional rods.

k. Inspections and testing. Inspection and testing of the system should be implemented as integral elements of the facility during the construction of the building or structure. To ensure that the implementation is accomplished in a timely manner, the construction efforts should be carefully monitored from the onset of excavation through completion of the facility. Prior to acceptance of the facility, the installation should be validated as acceptable using DA Form 7452-R shown in figure 3-5. The following guidelines are provided to aid in the inspection and checkout of the facility.

(1) Observe installation procedures. Specifically see that the requirements and recommendations outlined above are observed. Verify that ground rods conform to specified sizes. If the ground rods are driven in place, see that driving collars or nuts are used to prevent damage to the rods. Watch for bent and broken or bulged couplings between sections. Seriously weakened or damaged couplings should be replaced before driven below grade.

(2) Spot-check the resistance of rods as they are driven. Use the fall-of-potential method to determine the resistance of a rod when it reaches the design or specified depth. Project the net resistance of the total number of ground rods. This projection should indicate if the planned electrode subsystem will achieve 10 ohms (or less) resistance. As additional rods are driven, continue to spot check the resistance of individual rods by measuring the resistance at each successive fourth or fifth rod. This procedure will permit a decision to be made on the necessity for adjusting the electrode configuration (either adding to or subtracting from) to achieve the required resistance.

(3) See that cable interconnecting the rods is of a correct size (1/0 AWG). Inspect all connections between cable sections and all interconnections between cable and ground rods. All connections to be buried and subsequently made inaccessible must be welded or brazed. Restrict the use of clamps or bolted connections to locations which will remain accessible.

(4) Verify that provisions are made for interconnecting the earth electrode subsystem with metal utility lines, buried tanks, and other underground metals.

(5) Verify that risers or cables of appropriate size are installed for lightning down conductor, signal ground, and power system ground connections. Ensure that risers used for lightning down conductors are not used as part of the signal reference or fault protection subsystems.

EARTH GROUND ELECTRODE SUBSYSTEM CHECKLIST FOR NEW FACILITIES
For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY *Fort Tank*	2. DATE *(YYYYMMDD)* 20020228
3. LOCATION *Building 358*	4. INSPECTOR *Joe Sparks*
5. SOIL RESISTIVITY *(ohm-cm) (Obtain from site survey or from the measured resistance of a rod or group of rods)* *100*	6. RESISTANCE OF COMPLETED EARTH ELECTRODE SUBSYSTEM *(ohms)* *5*

7. SKETCH OF FINAL EARTH ELECTRODE SUBSYSTEM *(Show dimensions, locations of other buried metal objects, risers for lightning, power, or signal ground connections, and any ground wells.) (Corrected engineering drawings may be attached in lieu of sketch.)*

See attached drawing 001-50-6, 30 November 2001

COMPONENT IDENTIFICATION

8. GROUND RODS

8a. TYPE	8b. SIZE	8c. NUMBER OF ADDITIONAL RODS
copper strand	*1" X 10 feet*	*2*

8d. POSITIONED AND INSTALLED AS SPECIFIED	8e. PHYSICAL CONDITION
[X] YES [ ] NO	*no damage*

9. GROUND CONDUCTORS

9a. TYPE	9b. SIZE	9c. MATERIAL
stranded, bare	*1/0*	*copper*

9d. DISTANCE BETWEEN TWO SUCCESSIVE GROUND CONDUCTORS	9e. BURIED DEPTH
6 feet	*3 feet*

10. INTERCONNECTING CONDUCTORS

10a. TYPE	10b. SIZE	10c. MATERIAL
stranded, bare	*1/0*	*copper*

11. CONNECTORS/FITTINGS

11a. PROPER TYPE/SIZE/MATERIAL AS SPECIFIED	11b. MEASUREMENT OF RESISTANCE BETWEEN TWO CONNECTION POINTS
[X] YES [ ] NO	*0.1 ohms*

12. RISERS

12a. PROPERLY INSTALLED	12b. PROPERLY SIZED	12c. LOCATED AS SPECIFIED
[X] YES [ ] NO	[X] YES [ ] NO	[X] YES [ ] NO

13. FUTURE INACCESSIBLE JOINTS AND CONNECTIONS

13a. PROPERLY INSTALLED	13b. PROPERLY CONNECTED
[X] YES [ ] NO	[X] YES [ ] NO

14. GROUND WELLS

14a. INSTALLED AS SPECIFIED	14b. MEASURED RESISTANCE-TO-EARTH *(ohms)*
[X] YES [ ] NO	*5*

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Figure 3-5. Sample of completed DA Form 7452-R

(6) Once the complete minimum system is installed, measure the resistance to earth for the system using the fall-of-potential method. If the resistance is greater than 10 ohms, alternate methods as described above for reducing the resistance-to-earth shall be considered.

(7) Ensure that all changes or modifications are properly indicated on the facility drawings.

(8) Maintain a copy of all drawings, initial site surveys, checklists, and test data collected during construction in the facility records department.

l. Baseline configuration documentation. Documentation collected during the site surveys that provide the basis for the site conditions should be maintained in the facility records for future reference.

3-3. Fault protection subsystem

An electrical system ground is the connection of the electrical system to earth in such a manner that will limit the voltage imposed by lightning, line surges and unintentional contact with higher voltage lines; and stabilize the voltage to earth during normal operation. An equipment ground is the connection of conductive materials enclosing electrical conductors or equipment to limit the voltage to ground on these materials. A grounded conductor is a system or circuit conductor, which is intentionally grounded. A grounding conductor is a conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes. The purpose of the equipment fault protection subsystem is to ensure that personnel are protected from shock hazard and equipment is protected from damage or destruction resulting from faults that may develop in the electrical system. To accomplish this, ground connections must be adequate for both normal and fault currents and have sufficiently low impedance to facilitate operation of overcurrent devices under fault conditions. The fault protection subsystem includes the green wire and all exposed non-current-carrying metal parts of fixed equipment such as raceways and other enclosures which are likely to be energized under power fault conditions. Any conductor used for grounding purposes shall not penetrate any designated RF barrier, screen room, shielded enclosure etc., but shall rather be bonded to a welded stud on the barrier.

a. Typical configuration. The equipment fault protection subsystem consists primarily of the grounding conductors of the interior ac power distribution system. One of the major shortcomings in grounding systems is the interconnection and reversal of ac neutral and equipment grounding conductors of the ac power distribution at various power distribution panels and at equipment throughout a facility. These installation errors result in additional electrical noise and ac currents in the ground system. The equipment fault protection subsystem should generally follow a configuration from a central or main ground point which ideally should be at the primary power station transformer ground point. If an equipment grounding conductor is not available to the main ground point, the equipment grounding conductor should be bonded directly to the earth electrode subsystem at the communications building. The configuration consists of a central main or trunk lead from the power source with equipment grounding conductors to the various intermediate power panels and equipment. The equipment grounding conductor is carried along with the phase and neutral wires from the main ground point to the main circuit breaker panel, from there to intermediate circuit breaker panels to the equipment panels, and finally to the equipment.

b. Design considerations. A power system fault is either a direct short or an arc (continuous or intermittent) in a power distribution system or its associated electrical equipment. Figure 3-6 illustrates how personnel hazards are developed by improper wiring and fault conditions. The grounding system for transformers, switchgear, motors, etc. shall comply with the requirements of *NEC*® Article 250. These faults are hazardous to personnel for several reasons:

(1) Fault currents flowing in the ground system may cause the chassis of grounded equipment to be at a hazardous potential above ground if not properly grounded.

(2) The energy in a fault arc can be sufficient to vaporize copper, aluminum, or steel. The heat can present a severe burn hazard to personnel.

(3) There could be a fire hazard associated with any short circuit or arc.

(4) Burning insulation can be particularly hazardous because of the extremely toxic vapors and smoke which may be produced.

(5) Common causes of electrical system faults are:

(a) Rodents getting between ground and phase conductors

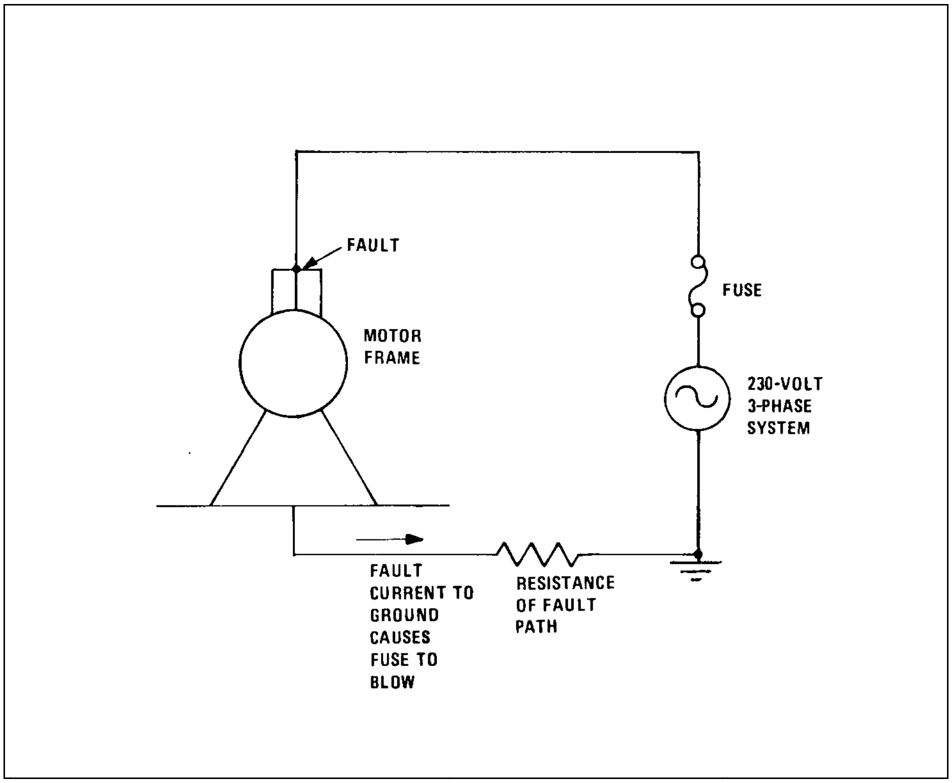


Figure 3-6. Grounding for fault protection

(b) Water infiltration

(c) Moisture in combination with dirt on insulator surfaces

(d) Breakdown of insulation caused by thermal cycling produced by overloads

(e) Environmental contaminants

(f) Damage during installation

(g) System age deterioration

(6) For a motor supply if one phase of the 230-volt line accidentally contacts the motor frame, and the motor is not grounded, its frame will rise to the circuit maximum phase-to-ground potential of 133 volts, and anyone coming in contact with it would be subject to a lethal shock if simultaneous contact is made with a grounded object. To prevent this situation from arising, the motor frame must be grounded via the equipment grounding conductor (green wire). The resistance of the fault path must be low enough to permit the fault current to trip the overload protector and interrupt the fault. If the resistance of the fault path is too large, the fault current will not be enough to trip the overload protectors. Thus to minimize both shock and fire hazards, the resistance of the fault path must be as low as possible. However, the fault protection subsystem normally does not depend on the earth electrode subsystem to trip overcurrent devices. The fault current normally flows through the green wire (grounding conductor) to the source side of the first service disconnect where the green wire and the neutral are tied together. The fault current then flows through the neutral to the transformer to complete the circuit. This path functions completely independent of the connection to the earth electrode subsystem. The earth electrode subsystem functions to limit the voltage difference between personnel and equipment, and prevent system voltage from rising above normal levels during fault conditions. The earth electrode subsystem is connected to the ac power system at the supply transformer neutral and the service entrance disconnect.

(7) Fault clearance in power distribution systems is normally provided by circuit breakers, fuses, or overload relays in each phase. These devices provide protection only if the fault current is sufficient to trip the over-current device. However, these protective devices may not act fast enough to protect personnel during accidental direct contact with energized circuits.

(8) Article 250-118 of the *NEC*® describes the types and materials used for equipment grounding conductors. Types include solid and stranded (insulated or bare) wire or other shapes, such as metallic tubes, pipes, and conduit. The grounding conductor types permitted by the *NEC*® also include various metal ducts, cable trays, and raceways; however, these types shall not be used in lieu of the equipment grounding conductors. The *NEC*® also permits/allows certain types of armored cable sheath be used as grounding conductors.

c. Typical components and installation details. The equipment fault protection subsystem consists primarily of the grounding conductors of the interior ac power distribution system. The grounding conductors are green insulated or bare wires running in the same conduit or duct with the neutral and phase conductors. Dedicated grounding conductors are preferred to reduce electromagnetic interference (EMI). Figures 3-7, 3-8, and 3-9 provide examples of equipment fault protection subsystems.

(1) To protect personnel from exposure to hazardous voltages, all exposed non-current carrying metallic elements located near the energized circuits shall be connected to ground. In the event of inadvertent contact between the "hot" lead and chassis, frame, or cabinet through human error, insulation failure, or component failure, a good, direct, known fault current path will be established to quickly remove the hazard. Also, according to *NEC*®, Article 250-24, the neutral conductor should be grounded at the service entrance disconnecting mean. If the transformer supplying the service entrance is located outside the building, an additional grounding electrode should be installed at the transformer and the grounded conductor of the transformer should be grounded to the newly added grounding electrode. Buildings having two or more service entrances are bonded to the building's common earth electrode subsystem.

(2) Metal boxes, fittings, and non-current-carrying metal parts of other fixed equipment do not require additional protection if mechanically connected to the grounded cable armor or bonded to the grounded members of the building. MIL-STD-188-124B, Grounding, Bonding and Shielding for Common Long Haul/Tactical Communication Systems Including Ground Based Communications-Electronics Facilities and Equipment, provides that the path to ground for circuits, equipment, and

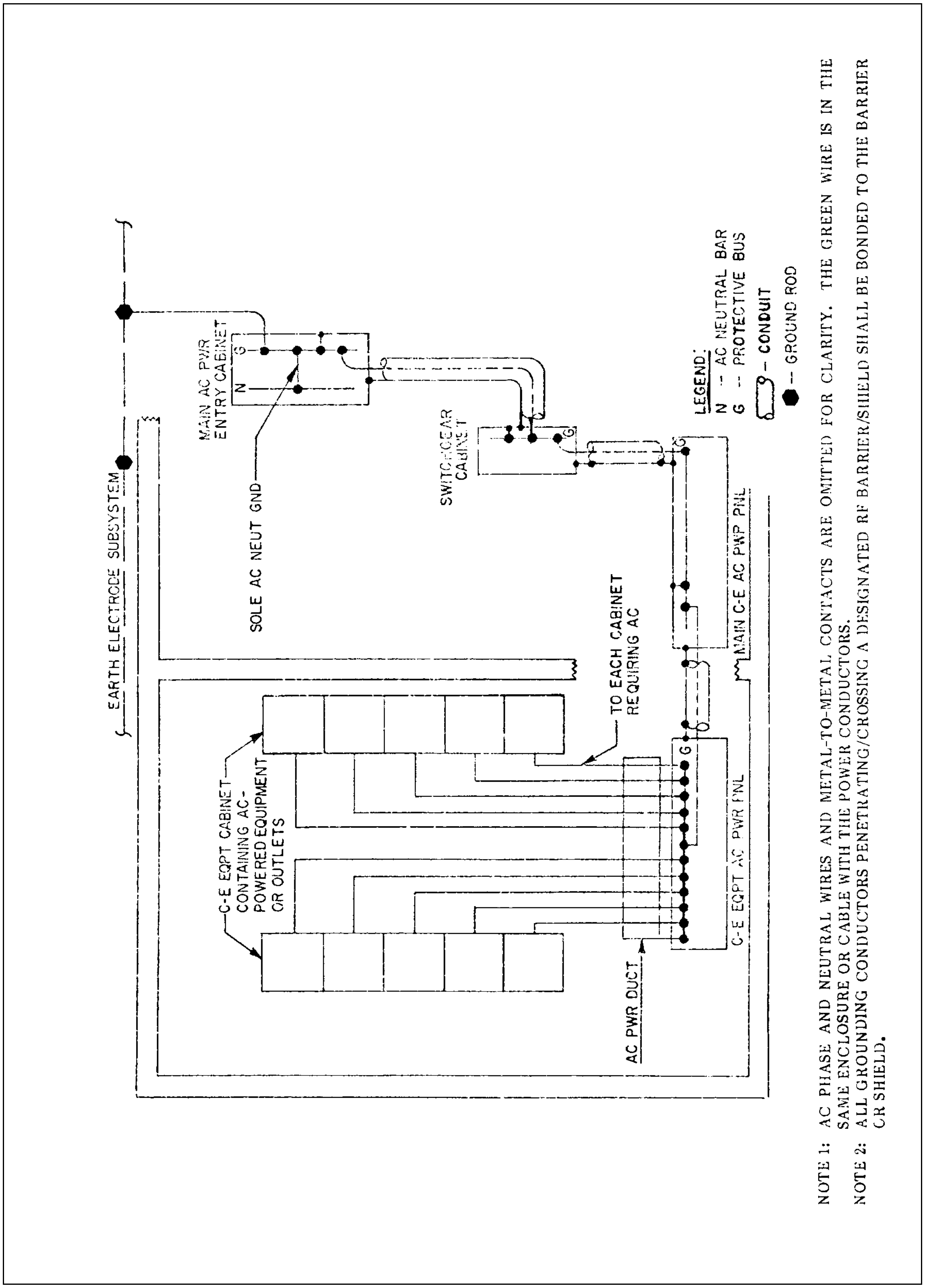


Figure 3-7. Typical equipment fault protection subsystem

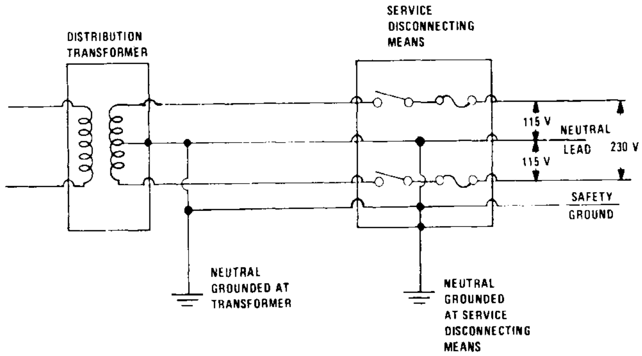


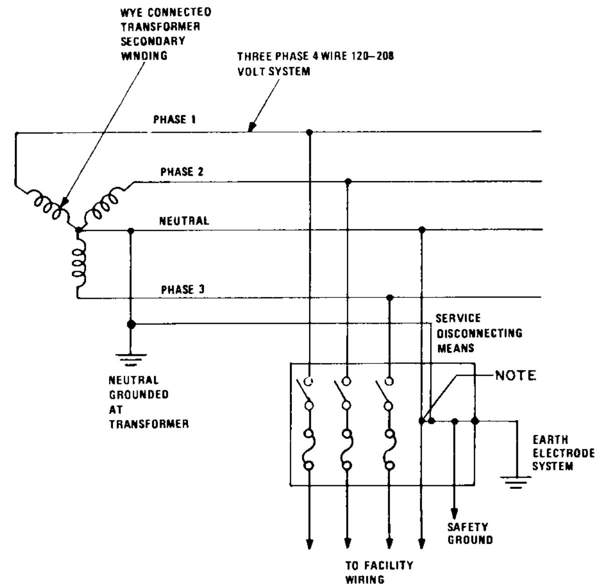
Figure 3-8. Single-phase 120/240 volt ac power ground connection

conductor enclosures be permanent and continuous. The path must have (1) the capacity to conduct safely any fault current likely to be imposed upon it, and (2) sufficiently low impedance to limit voltage to ground and to aid the operation of circuit protective devices.

(3) Experience with military communications equipment (CE) facilities has proven that a low-noise, low-impedance equipment fault protection subsystem can be maintained over a prolonged period of time if separately designed and installed with ground conductors. Therefore, a separate equipment fault protection conductor shall be included with the ac power distribution if not provided in the power cable. A grounding (green) wire should be used and installed in the same conduit as the other ac wires. When ferrous ducts or conduits are used to shield the neutral and phase conductors, the lowest impedance will result when this grounding conductor is installed in the same conduit. The impedance can be further decreased if the grounding conductor is wrapped around the other conductors and bonded to the duct or conduit at both ends. In a correctly installed power distribution system, there should be no power current on the grounding conductor, except during an abnormal condition. It should be noted that there are two types of abnormal conditions causing overcurrent devices to operate. The first is an overload condition in equipment. In this case, the high current is on the neutral and phase leads. The second abnormal condition is where a phase or hot lead is inadvertently grounded. The high current in this case is on the hot lead and the grounding conductor. In both cases, the overcurrent protective device, usually a circuit breaker, is opened in the phase or hot lead. Due to the high currents that can flow either on the phase leads, neutral, or grounding conductor, it is recommended that a 2-inch separation be maintained between power runs and signal runs when neither is in conduit.

(4) Electrical supporting structures such as conduit, cable trays or raceways, wiring system enclosures, and metallic power cable sheaths should be electrically continuous and are to be bonded to the facility ground system at multiple points. In the event of a fault, this continuity will prevent these structures from rising to a hazardous potential.

(5) For service entrances, the ac neutral lead can be grounded at the first service disconnect means. In this case, the ac neutral also serves as a grounded conductor back to the source. For best results, the ac neutral (grounded) and green (grounding) wire should be grounded at the service transformer and the first



NOTE: Lift when single transformer supplies power to more than one building or because of objectionable current, noise or interference.

Figure 3-9. Three-phase 120/208 volt ac power system ground connections

service disconnect means through the five-wire distribution system. All distribution neutrals are to be isolated from equipment and structural elements except for the connection at the first service disconnect. If a single common service supplies two or more separate buildings, the connection to the grounding electrode and grounding or bonding of equipment, structures or frames required to be grounded or bonded must be accomplished in different ways, depending on whether the equipment grounding conductor is installed with the supply or is not installed with the supply. If a single service is installed with an equipment grounding conductor to a second building, the grounded conductor (neutral) is not permitted to be connected to the equipment grounding conductor or the grounding electrode system as shown in figure 3-10. If a single service is not installed with an equipment grounding conductor to a second building, the grounded conductor (neutral) is permitted to be connected to the equipment grounding conductor or the grounding electrode system as shown in figure 3-11.

(6) Connect the ground terminals of convenience outlets to the facility ground system with the green wire specified by the *NEC*®. Do not use “wiremold” or “plugmold” distribution strips, which depend upon serrated or toothed fingers for grounding. “Wiremold” or “plugmold” is commonly used to supply high-density 120V receptacles for laboratories and work areas. Wiremold Company catalog number V20-C2 illustrates this product. Effectively ground the ground terminals on such strips with an auxiliary grounding conductor equivalent to the green wire requirements of Article 250 of the *NEC*®.

(7) For a direct current (dc) power system, ground one leg with a single connection to the earth electrode subsystem. The *NEC*® requires all two-wire dc systems operating between 50 to 300 volts be grounded, and requires all three-wire dc systems to be grounded. The size of the grounding conductor

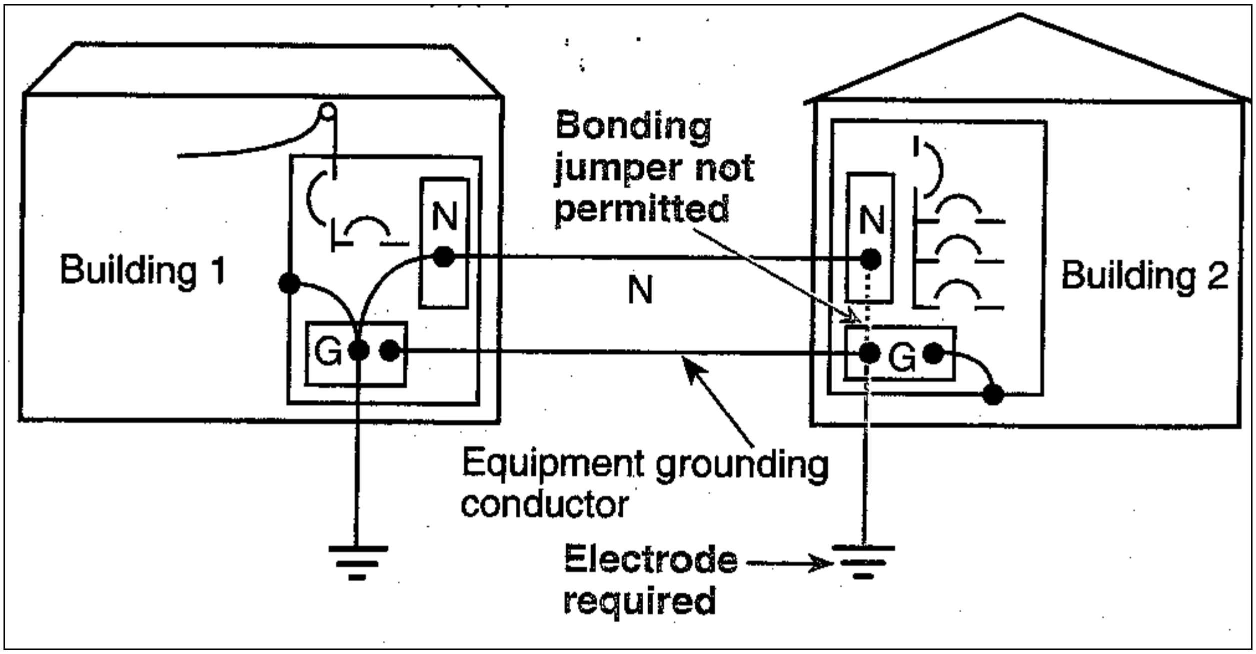


Figure 3-10. Single service entrance with common equipment grounding conductor

shall not be smaller than the largest conductor for two-wire dc systems, and shall not be smaller than the neutral conductor for all three-wire dc systems. Whether grounded at the source, the first system disconnection means or overcurrent device, or by other means that accomplish equivalent system protection, provide a dedicated current return conductor from the load to the source to assure that the dc load current in the facility ground system or the lower frequency signal ground network is minimized.

(8) On-site power generation requires grounding. The frames and housing of ac standby generators should be grounded as prescribed by the *NEC*®. Ground the neutral to the facility main ground plate or to the earth electrode subsystem, whichever is closest. When generators are connected in parallel, interconnect the neutrals and ground them to the facility's earth electrode subsystem with a common grounding conductor.

(9) For metal poles supporting outdoor lighting fixtures, ground pole to a grounding electrode in addition to separate equipment grounding conductor run with supply branch circuit.

(10) Bond grounding conductors, including grounding-conductor conduits, to lightning protection down conductors or lightning protection grounding conductors in compliance with National Fire Protection Association (NFPA) 780, Standard for the Installation of Lightning Protection Systems (1997). Bond electric power system ground directly to lightning protection system grounding conductor at closest point to electric service grounding electrode. Use bonding conductor sized same as system grounding conductor and install in conduit.

(11) Electrical raceways require grounding to ensure the complete low impedance path to ground is maintained. The conduit is grounded to the power panel at each end, but it is not used in lieu of a grounding conductor, which continues through the conduit to the equipment ground bus bar.

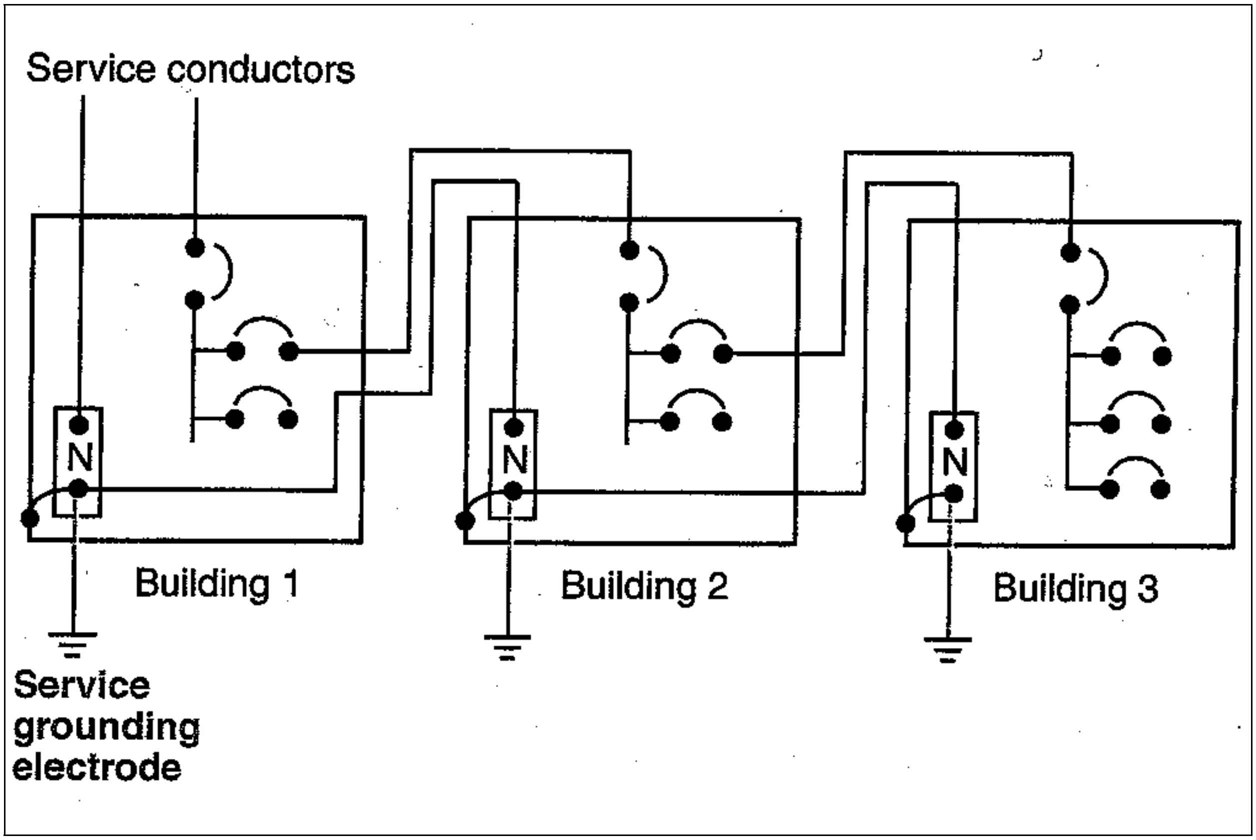


Figure 3-11. Single service entrance without common equipment grounding conductor

(a) All metal conduit is to be grounded, regardless of whether it is used for enclosing power cables or for signal and control cables.

(b) All joints between sections of conduit and between conduit, fittings, and boxes should be made electrically continuous when they are installed.

(c) All pipe and locknut threads should be thoroughly cleaned before they are engaged and then tightened firmly.

(d) Gouging locknuts must positively penetrate all paint or other non-conductive finishes.

(e) Any joints not inherently continuous should be bonded with jumpers of No. 12 AWG or larger copper wire. These jumpers should be welded or brazed in place or attached with clamps, split bolts, grounding bushings, or screws and lockwashers.

(f) Protect the bonds against weather, corrosion, and mechanical damage.

(g) Firmly tighten the screws on the cover plates of pull boxes, junction boxes, and outlet boxes.

(h) All conduit brackets and hangers should be securely bonded to both the conduit and to the structural member to which they are attached. Bond conduit runs, to include the individual sections, couplings, line fittings, pull boxes, junction boxes, outlet boxes, etc., to the facility ground system should be at intervals not exceeding 15 meters (50 feet). The resistance to each connection should not exceed 5 milliohms.

(i) All cable tray systems shall be electrically continuous by bonding together each individual section. Bond each support bracket or hanger to the cable trays which they support. Connect the cable tray assemblies to the facility ground system with copper cables or equivalent conforming to the 2000 cmil per foot criterion. Make the connections within two feet of each end and at intervals not exceeding 15 meters (50 feet) along the run. Where metal covers are used, they should be securely bolted in place.

(12) All metallic pipes and tubes (including conduit) and their supports should be electrically continuous and are to be bonded to the facility ground system at least at one point. If any run of metal pipes or tubes exceeds 3 meters (10 feet) in length, it should be bonded to the facility ground system at each end. Also, longer runs should be bonded to the facility ground system at intervals of approximately 45 meters (150 feet).

(a) At indoor locations, these bonds may be made with clamps which provide continuous pressure. Pipes installed out of doors should be bonded to the facility ground system at entry point or wherever feasible by welding or brazing. Compatible stainless steel straps may be used with stainless steel pipe. In the event that a direct bond cannot be made, zinc-plated hose clamps or stranded, bare copper, untinned bond straps may be used. All bonds should be adequately protected against corrosion in humid or corrosive environments.

(b) Joints in metal pipes and tubes should have a dc resistance no greater than 5 milliohms. In the case of threaded joints, the threads should be cleaned and firmly tightened (200 ft-lbs for rigid wall conduit) and protected against corrosion. Leaded or caulked joints, flared and other compression fittings, and 0-ring fittings should all be measured to verify that the joints have a dc resistance no greater than 5 milliohms.

(13) Other equipment/installations requiring grounding and bonding include the following.

(a) The frames of motors, generators, and other types of electrical rotating machinery are to be connected to the facility ground system in accordance with the NEC requirements.

(b) Ground all enclosures of electrical and electronic wiring and distribution equipment in accordance with *NEC*® Article 250.

(c) The armor on electrical power cables should be bonded to the facility ground system at each end if the cables are 3 meters (10 feet) or longer. Provide supplemental connections at intervals not exceeding 15 meters (50 feet). The resistance of each connection should not exceed 5 milliohms.

(d) To protect personnel from exposure to hazardous voltages, all exposed metal elements of equipment and supporting structures shall be interconnected by an equipment grounding conductor (green wire) from the ac power distribution system and referenced back to the power source. The grounding requirements of a transportable facility installed in the field and operating from transportable engine generators is relatively simple. The primary requirement is to ensure that all vans, vehicles, trailers, and engine generator units are interconnected through an equipment grounding conductor (green wire) network, and the power neutral is grounded from a common bus that is connected to an earth electrode at the generator. Where parts are moveable or subject to vibration, metal straps may be used in lieu of the green wire. When transportable equipment is powered from a commercial base ac source or is integrated

into a permanent installation with non-transportable equipment, personnel protection requirements become more complex. When part of a fixed installation, the transportable equipment shall be integrated into the facility ground system by extending the earth electrode subsystem to provide connections for the transportable equipment. All metallic components of the transportable equipment shall be interconnected through the equipment fault protection subsystem and bonded to the earth electrode subsystem at the main power panel, or back to the primary power source through the ground conductor of the power distribution cable.

d. Inspections. Inspections of the fault protection subsystem should be implemented as integral elements of the facility during the construction of the building or structure. To ensure that the implementation is accomplished in a timely manner, the construction efforts should be carefully monitored. Prior to acceptance of the facility, the installation should be validated as acceptable using DA Form 7452-1-R shown in figure 3-12. The following guidelines are provided to aid in the inspection and checkout of the facility.

(1) Specifically see that the requirements and recommendations outlined in paragraph 3.3.c. (1) through 3.3.c. (13) are observed. Verify that grounding conductors conform to the sizes specified.

(2) Verify that the grounding conductors are routed along the shortest and straightest paths possible, except as otherwise indicated. Avoid obstructing access or placing conductors where they may be subjected to strain, impact, or damage.

(3) Verify that any underground ground conductors are bare copper wire sized as specified and are at least 24 inches (600 mm) below grade.

(4) Verify bonds to metal water pipes.

(5) Verify that bonds have been made to pipes of each interior metal piping system present and to metal air ducts. These bonds shall be located between equipment grounding conductors of associated pumps, fans, blowers, electric heaters, and air cleaners. Bonds shall be made by using braided-type bonding straps.

(6) Verify that connections are made with galvanically compatible materials.

(7) Verify exothermic-welded connections comply with manufacturer's written instructions. Welds that are puffed up or that show convex surfaces indicating improper cleaning are not acceptable.

(8) Verify proper lugs are used for the appropriate cable size.

(9) Verify conduits are properly terminated and bonded to the metal housings. Verify the conduit to be electrically non-continuous and that both entrances and exits are properly bonded with grounding bushings and bare grounding conductors, except as otherwise indicated.

(10) Verify that screws and bolts for grounding and bonding connectors and terminals are installed in accordance with manufacturer's published torque-tightening values. Where these requirements are not available, use those specified in Underwriters Laboratories (UL) UL 486A, Wire Connectors and Soldering Lugs for Use with Copper Conductors, Ninth Edition (1998), and UL 486B, Wire Connectors for Use with Aluminum Conductors, Fourth Edition (1997).

GROUND FAULT PROTECTION SUBSYSTEM CHECKLIST FOR NEW FACILITIES

For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY	2. DATE *(YYYYMMDD)*
Fort Tank	20020228
3. LOCATION	4. INSPECTOR
Building 1929	*Lou Swire*

5. SKETCH THE LAYOUT OF THE ACTUAL ELECTRICAL GROUND FAULT PROTECTION SUBSYSTEM. IF AN ENGINEERING DRAWING EXISTS, UPDATE IT WITH THE ACTUAL DATA. THIS SHOULD INCLUDE ALL GROUNDED *(Neutral)* AND GROUNDING (Green) CIRCUITS FROM THE MAIN INPUTS *(Feeding the facility)* TO THE LOAD CIRCUITS.

See attached drawing 001-50-6, 30 November 2001

6. CHECK ALL GROUNDED CIRCUITS FOR PROPER INSTALLATION, CONTINUITY, AND CORRECT TYPES, SIZES, AND MATERIAL AS SPECIFIED. RECORD ALL DEFICIENCIES.

LOCATION	DEFICIENCIES
Panel A-3	*Grounded conductor is size #2 instead of 2/0 as specified in DWG EE-1*
Panel B-5	*Grounding conductor does not run in same conduit as phases conductor*
Panel C-7	*No ground bus exists. All green conductors were connected to neutral bus.*

7. CHECK ALL ELECTRICAL GROUND FAULT PROTECTION COMPONENTS/DEVICES FOR SIGNS OF OVERHEATING, BURNING, RODENT, WATER INFILTRATION, ENVIRONMENTAL CONTAMINANTS, AND INSULATION DAMAGE. RECORD ALL UNDESIRABLE SITUATIONS.

LOCATION	DAMAGE
Panel E-1	*Ground bus has signs of burning*
Panel E-3	*Neutral bus corroded*

8. DETERMINE AND RECORD CONNECTION TO EARTH ELECTRODE SUBSYSTEM

LOCATION	CONNECTIONS	CONDUCTOR SIZES
Main switchgear	*Ground bus of SWG*	*(3) 500 MCM*
Gen switchgear	*Ground bus of SWG*	*(3) 500 MCM*

9. MEASURE AND RECORD THE NEUTRAL AND GROUND CURRENTS AT ALL PANEL BOARDS

LOCATION	CURRENT READING	NOTES
Panel A-2	*I(N) = 30 A, I(G) = 0.5 A*	*Supply Warehouse B-1*
Panel B-4	*I(N) = 50 A, I(G) = 10 A*	*Supply ADP Room B-5*
Panel C-6	*I(N) = 42 A, I(G) = 0.7 A*	*Supply BOQ 3*

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Figure 3-12. Sample of completed DA Form 7452-1-R

(11) For compression-type connections verify that the proper hydraulic compression tools provide correct circumferential pressure for the connectors. Verify the tools and dies are as recommended by the

manufacturer of the connectors. Provide embossing die code or other standard method to make a visible indication that a connector has been adequately compressed on grounding conductor.

(12) Insure that all changes or modifications are properly indicated on the facility drawings.

e. Tests. Testing shall be performed by qualified and trained personnel.

(*1)* The following safety precautions should be followed when testing the ground system.

(a) When testing earth resistance, remember that during fault conditions, dangerous voltages may exist between a system ground and a remote point being tested. Care should be taken when connecting leads and test equipment. Avoid as much contact with the leads and probes as possible.

(b) Most of the earth resistance is located close to the grounding system due to the "hemisphere effect." Around a grounding hemispherical electrode, the resistance of the soil is the sum of the series resistances of virtual shells of earth, located progressively outward from the electrode. The shell nearest the electrode has the smallest circumferential area or cross section, so it has the highest resistance. Successive shells outside this one have progressively larger areas, and thus progressively lower resistances. As the radius from the electrode increases, the incremental resistance per unit of radius decreases effectively to nearly zero. When a ground fault occurs, the majority of the voltage drop is close to the system. Caution should be used when approaching a live ground.

(c) At stations where the fence is not connected to the station ground, a dangerous voltage can develop under fault conditions between the fence and station ground. Do not touch both at the same time.

(d) Surge and switching effects in transmission lines may induce dangerous spikes in the test leads strung under the line. Care should be exercised in handling these test leads.

(e) Tests should not be performed during a thunderstorm.

(f) Rubber gloves, boats, an insulated platform, etc., capable of protecting the operator against full-line voltage, are recommended for protection.

(2) The completed grounding system shall be megger tested at each location where a maximum ground-resistance level is specified by the installation design documents, at service disconnect enclosure grounding terminal, and at ground test wells. Measure ground resistance not less than 2 full days after the last trace of precipitation, and without the soil being moistened by any means other than natural drainage or seepage and without chemical treatment or other artificial means of reducing natural ground resistance. Perform tests by the two-point method according to IEEE 81, Guide for Measuring Earth Resistivity Grounding Impedance and Earth Surface Potentials of Ground Systems (1983). The two-point method provides a pass/fail indication of ground resistance and is easier to perform than the three-point method. Maximum grounding to resistance values are as follows.

(a) Equipment rated 500 kVA and less: 10 ohms

(b) Equipment rated 500 to 1000 kVA: 5 ohms

(c) Equipment rated more than 1000 kVA: 3 ohms

(d) Unfenced substations and pad-mounted equipment: 5 ohms

(e) Manhole grounds: 10 ohms

(3) Measure the ground path resistance of all branches of the grounding system from the point of connection, on the structure, equipment enclosure, or neutral conductor, to the earthing connection. The earthing connection may be the top of a single ground rod, a water pipe, a counterpoise, or a ground grid.

(4) Measure the resistance of the earthing connection whether it is a ground rod, a water pipe, a counterpoise, or a ground grid to the earth itself.

(5) Wherever the total resistance of the total ground circuit is in excess of the values established, measure resistance of individual portions of the circuit to determine the point or points where resistance is excessive and corrective action can be taken.

(6) Measure resistance between gates and gateposts to ensure that flexible ground connections are adequate. Resistance higher than one-half ohm indicates a deficiency.

(7) Measure resistance between operating rods and handles of group-operated switches and the supporting structure to determine that the flexible connections are adequate. Resistance higher than one-half ohm indicates a deficiency.

(8) Measure resistance of all bonds between metallic-cable sheathing and its ground path. Resistance higher than one-half ohm indicates a deficiency.

(9) All methods of measuring ground resistance are similar in that a suitable source of current is necessary. Auxiliary reference grounds and test instruments are necessary for American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers (IEEE) ANSI/IEEE 80, IEEE Guide for Safety in AC Substation Grounding, methods. The following methods are suitable for measuring the resistance of isolated ground rods or small grounding installations. Precision in measurements is difficult to obtain. Normally an accuracy of 25 percent is sufficient, since the surrounding soil will not have consistent values of temperature, moisture, and depth.

(a) A usual way to measure the ground resistance is with a low-range, self-contained, portable earth-tester instrument such as the “Megger” ground tester. The manufacturer’s instructions should be followed in the use of this instrument.

(b) The resistances of the ground circuits are determined from the meter readings and these values are then used in calculating resistance (R). Stray alternating currents (ac) of the same frequency as the test current, if present, will introduce some error in measurements.

(c) Where accurate measurements of extensive low-resistance grounding systems are required, more elaborate test methods and equipment are needed using considerably larger separation distances between test electrodes. Normally large facility substations are tested with the fall-of-potential method.

(d) To allow for seasonal variations it is recommended that tests be made at the same time each year or for each season of the year to allow for accurate comparison.

(e) Tests should be performed in accordance with written procedures. Provide adequate safety precautions as all electrical conducting paths for overvoltage and fault currents are connected to the substation grid.

(11) Maintain a copy of all drawings, initial site surveys, checklists, and test data collected during construction in the facility records department. Prepare test reports, certified by the testing organization, of ground resistance at each test location. Include observations of weather and other phenomena that may affect test results. Describe measures taken to improve test results.

3-4. Lightning protection subsystem

A lightning protection subsystem is frequently installed to protect the structure, personnel, and equipment of the C4ISR facility from damage due to lightning discharges. A major element of this protection is achieved by providing a means by which a lightning stroke can bypass the facility and enter the earth without causing damage. The stroke current must first be intercepted before it penetrates the structure. Air terminals are provided for this purpose. Preferential paths must then be offered which the stroke current will follow instead of any others. To provide these preferred paths, down conductors are designed to have large diameters and are routed to be as straight and short as possible. Finally, a low impulse impedance connection with the earth must be made.

a. Typical configuration. To provide the most effective safeguard, a lightning-protection system must be appropriate for the type of structure and its construction characteristics. It has been shown that a modest lightning stroke of 10,000 amperes (A) develops a 2,000 kV voltage when it terminates on the phase conductor of a transmission line. Obviously, lines and equipment cannot be insulated to withstand voltages in this range. A more practical alternative is to limit voltages to a much lower level. This involves two basic principles - the use of masts and overhead ground wires to shield equipment and circuits from direct strokes; and the application of arresters to limit surge voltages to levels well below practical equipment insulation levels.

(1) The oldest and most commonly used protection method is the conduction system, sometimes termed as the Franklin Rod or Faraday Cage system.

(a) Air terminals (lightning rods) on the structure roof are connected to a grid of interconnecting (coursing) conductors, which connect to down conductors that extend down to earth and connect to appropriate grounding electrodes. The grounding electrodes can be individual ground rods or a conductive ring buried around the building perimeter or both.

(b) All system components are made of copper, anodized aluminum, or stainless steel.

(c) To complete the conventional lightning-protection system installation, all metallic elements (roof fans, vents, etc.), grounded or isolated, which are located on the roof or in the exterior walls near the down conductors, must be bonded to the down conductors because the possibility of a sideflash exists. A sideflash is an arc caused by a difference in potential between a down conductor and a metallic element. The bonding eliminates potential difference and prevents high current flow from damaging these components.

(2) Recent changes in standard guidelines have redefined the outline of the zone protected by any one standard air terminal. Originally, the accepted standard indicated that the area protected was defined by a 60° cone starting at the tip of the air terminal, surrounding the terminal, and extending to earth, without regarding the terminal height. Now, however, research and better data define the protected zone as an area under an arc that has a maximum radius of 150 feet and is tangent to the earth while touching the tip of an air terminal. This is important for structures exceeding 150 feet in height because additional air terminals must be installed at an appropriate intermediate level, as well as at roof level. Figure 3-13 illustrates the 150-foot radius of protection.

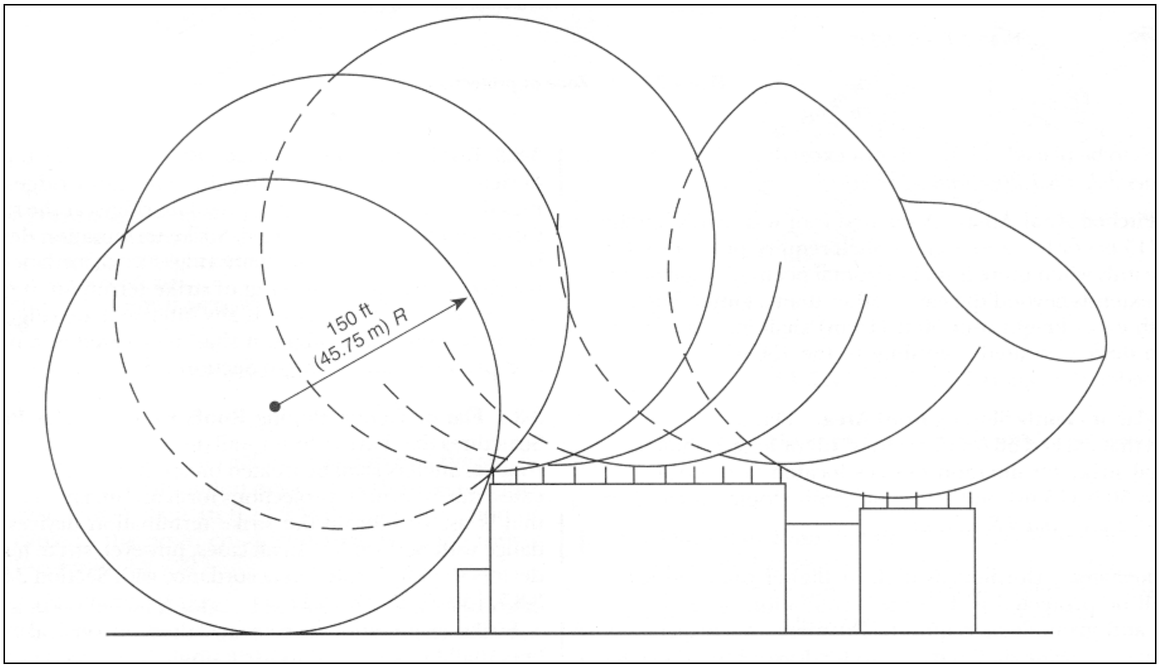

Figure 3-13. 150-foot radius of protection

(3) Other protection requirements for high-rise buildings include the electrical interconnection of the steel column components or installation of conductive loops around the building at vertical intervals not exceeding 60 feet. A bonding conductive loop must also be made at ground level and at roof level. Furthermore, all grounded building elements (roof fans, vents, etc.) on building exterior walls within 12 feet of the main roof must be connected to the protection system. Also, buildings over 75 feet high must use larger system components per the requirements of the Standard for the Installation of Lightning Protection Systems, NFPA 780.

b. Design considerations. The degree to which lightning protection is required, is a subjective decision requiring an examination of the relative criticality of the structure location and its contents to the overall mission of the facility. Those structures containing elements vital to the operational mission such as air traffic control towers, radar installations, navigational aids, and communications centers are examples of facilities, which obviously must be protected. However, every building or structure does not require that a lightning protection system be installed. For example, buildings primarily used for the storage of non-flammable materials do not have a critical need for protection. Three of the factors to consider in ascertaining whether a given structure should have a lightning protection system installed or in determining the relative comprehensiveness of the system are the relative threat of being struck by lightning, the type of construction, and the nature of the facility.

(1) The relative likelihood of a particular structure being struck by lightning is a function of the isokeraunic level, i.e., the thunderstorm activity of the locality and the effective height of the structure. Average thunderstorm activity can be determined from isokeraunic maps. Figure 3-14 shows the mean annual number of days with thunderstorms based on the period 1948-1972. The frequency of strikes can then be estimated. Use this estimation as one of the inputs to the decision process.

(2) A structure, for lightning protection purposes, is defined as a building mast, tower, or similar self-supporting object other than power lines, power stations, and substations. To provide minimum

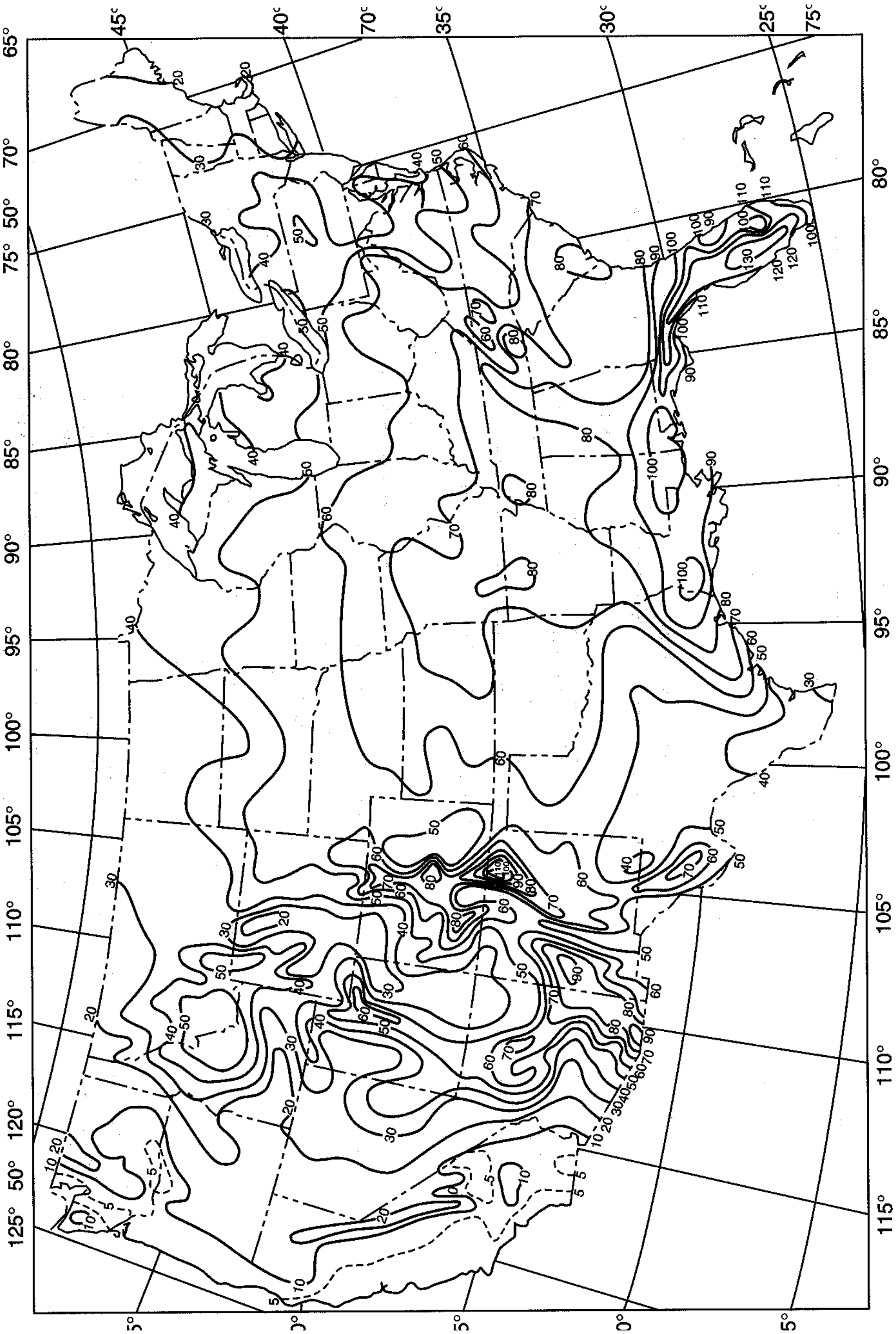

Figure 3-14. Mean annual number of days with thunderstorms based on the period 1948-1972

protection for structures against direct lightning strikes, four requirements must be fulfilled - an air terminal must be provided to intentionally attract the leader stroke, a path must be established that connects this terminal to earth with such a low impedance that the discharge follows it in preference to any other, a low resistance connection must be made with the earth electrode subsystem, and a low impedance interface must be established between the earth electrode subsystem and earth. Steel frame buildings with metal outer coverings offer the greatest inherent protection against lightning damage. Steel towers also exhibit a high immunity to structural damage. Additional protection for these type buildings will probably be required only for very critical facilities in highly exposed locations. Steel frame buildings with non-conductive, but non-flammable, outer coverings (like brick or other masonry) also offer a high degree of protection against lightning damage. The greatest hazard is posed by pieces of masonry being dislodged by stroke currents passing through the outer coverings to reach the structural steel underneath. Minimal protection consisting of interconnected air terminals to down conductors and steel support columns will be sufficient to prevent this type of structural damage. Buildings constructed of non-conductive materials such as wood, concrete blocks, or synthetic materials are the most susceptible to destructive damage. A complete auxiliary protection system will be required to prevent lightning damage to buildings utilizing this type of construction.

(3) Methods used to protect outdoor equipment vary depending on the location of the equipment. If the equipment were located in close proximity to a structure, which is being protected, it would be prudent to include the equipment protection within the zone of influence of the structure. Otherwise this equipment may be protected in the same way as overhead lines, transmission lines, substations, or high towers. In these cases a protective shielding cable sometimes called a “skywire” is usually installed. It is a well-grounded bare conductor, usually mounted several feet above the conductors or equipment to be protected. When lightning strikes in the vicinity, induced voltage surges tend to be carried by the shielding skywire instead of the protected conductors or equipment.

c. Protection components and installation details. Lightning protection systems are typically comprised of the following major components.

(1) Air terminals (lightning rods) must intercept, or divert to themselves, any lightning stroke that might otherwise strike the building or structure being protected. Antennas and their associated transmission lines/supporting structures shall be protected by air terminals rather than be dependent upon transient protection/suppression devices.

(a) Erect air terminals on the points of highest elevation and on other exposed areas to intercept the stroke before it has an opportunity to damage the structure, equipment, or components mounted thereon. The terminal points must be placed high enough above the structure to eliminate the danger of fire from the arc.

(b) To keep from exploding, igniting, or otherwise being destroyed, air terminals should be made of copper, aluminum, brass, or bronze. The minimum sizes are 1.27 cm (1/2 inch) in diameter for solid copper, brass, or bronze rods and 1.6 cm (5/8 inch) in diameter for solid aluminum rods.

(c) Air terminals must extend at least 25.4 cm (10 inches) directly above the object being protected and be of sufficient height so as to provide a 1:1 zone of protection for adjacent objects (antennas and associated support/control towers, etc). Rather than choosing the shortest terminal, which will provide this minimum height, all parts of the structure must be checked graphically or analytically to determine if the zone of protection provided by the terminal is adequate. Where taller terminals are required to provide complete protection, adequate support and bracing must be provided.

(d) Where air terminals are mounted on or very near [less than 1.5 meters (5 feet)] to vents or stacks that emit potentially explosive or ignitable dusts, vapors, or gases, provide additional clearance. Over hooded vents emitting explosive substances under natural draft, the air terminals should extend at least 1.5 meters (5 feet) above the opening. Above open stacks emitting explosive substances under forced drafts, air terminals should extend at least 4.5 meters (15 feet) above the opening.

(e) Locate air terminals along the ridges of gable, gambrel, and hip roofs as shown in figures 3-15 and 3-16. Place them on the corners and along the edges of gently sloping roofs having a span of 40 feet or less with a rise-to-run ratio, i.e., pitch, of one-eighth or less or having a span greater than 40 feet and a rise-to-run ratio of one-quarter or less.

(f) On flat roofs position the air terminals around the perimeter as shown in figure 3-17. Provide additional air terminals placed at 50-foot intervals over the interior of flat and gently sloping roofs which exceed 50 feet in width.

(g) Terminals are to be provided within 2 feet of corners, the end of ridges, or edges of main roofs.

(h) Terminals less than 24 inches in height are to be spaced 20 feet or less. Terminals 24 inches or taller may be placed at intervals not exceeding 25 feet.

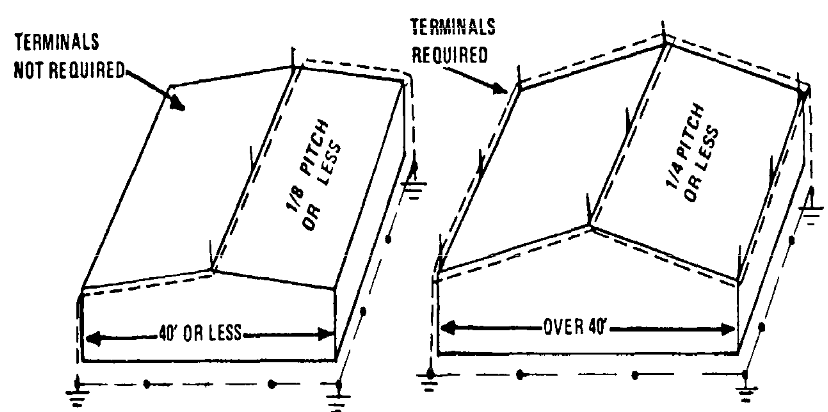

Figure 3-15. Location of air terminals on gently sloping roofs

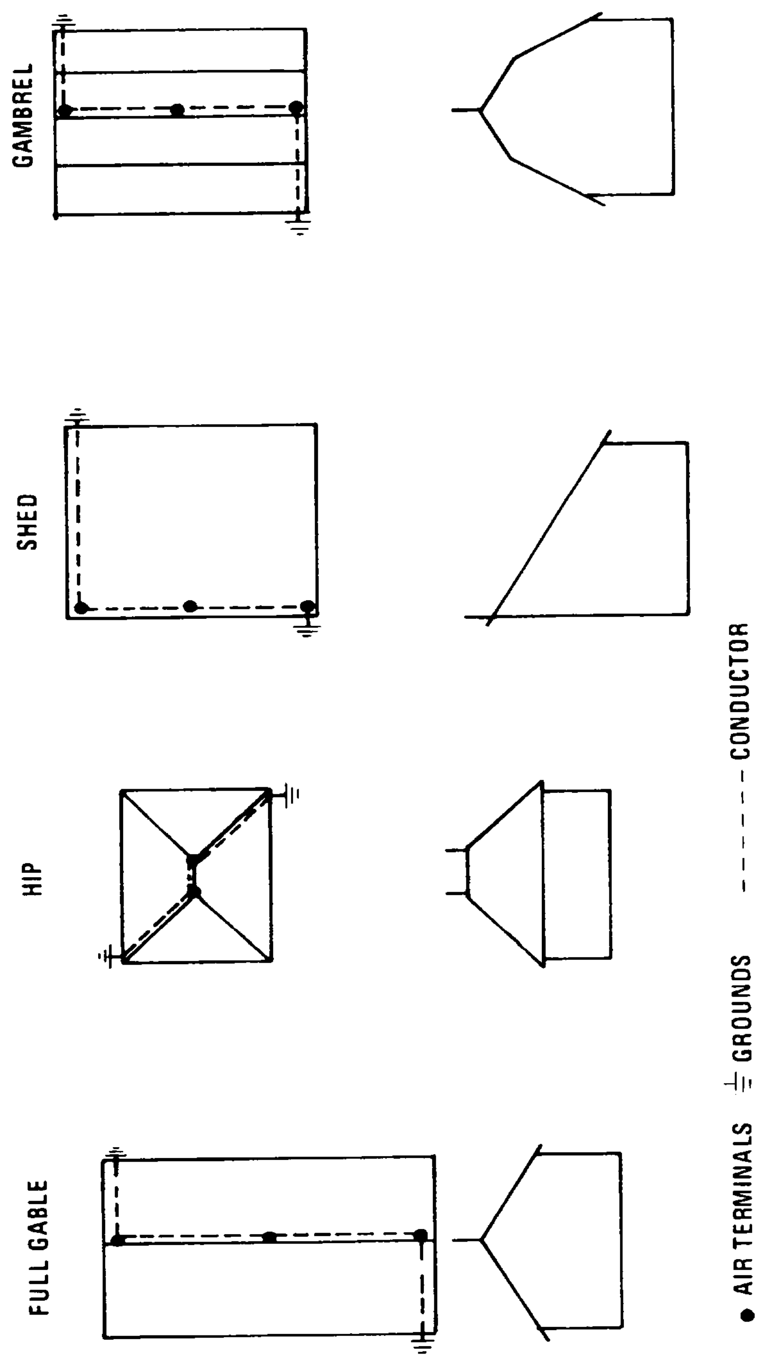

Figure 3-16. Location of air terminals for common roof types

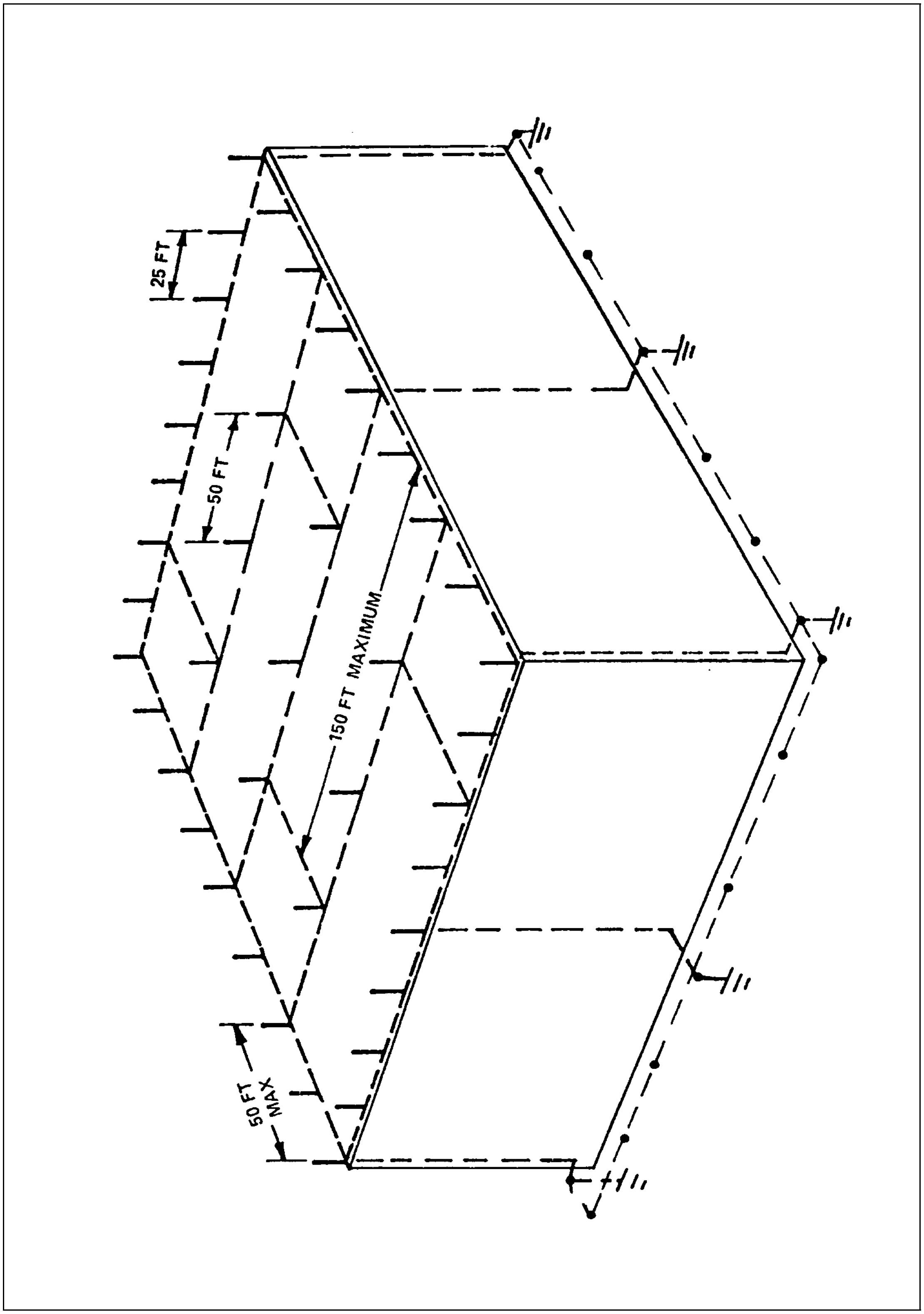

Figure 3-17. Air terminal placement on flat-roofed structures

(i) Ensure that no part of the structure extends outside the zone of protection established by the air terminals. For structures with multiple-level roofs no more than 50 feet (15 meters) in height, the zone of protection shall form a cone having an apex at the highest point of the strike termination device, with walls forming approximately a 45-degree (1:1 slope) or 63-degree (1:2 slope) from the vertical. Structures that do not exceed 25-feet (7.6 meters) are considered to protect lower portions of a structure located in a one-to-two (1:2) zone of protection as shown in figures 3-18 and 3-19. Structures that do not exceed 50-feet (15.24 meters) are considered to protect lower portions of a structure located in a one-to-one (1:1) zone of protection as shown in figures 3-20 and 3-21.

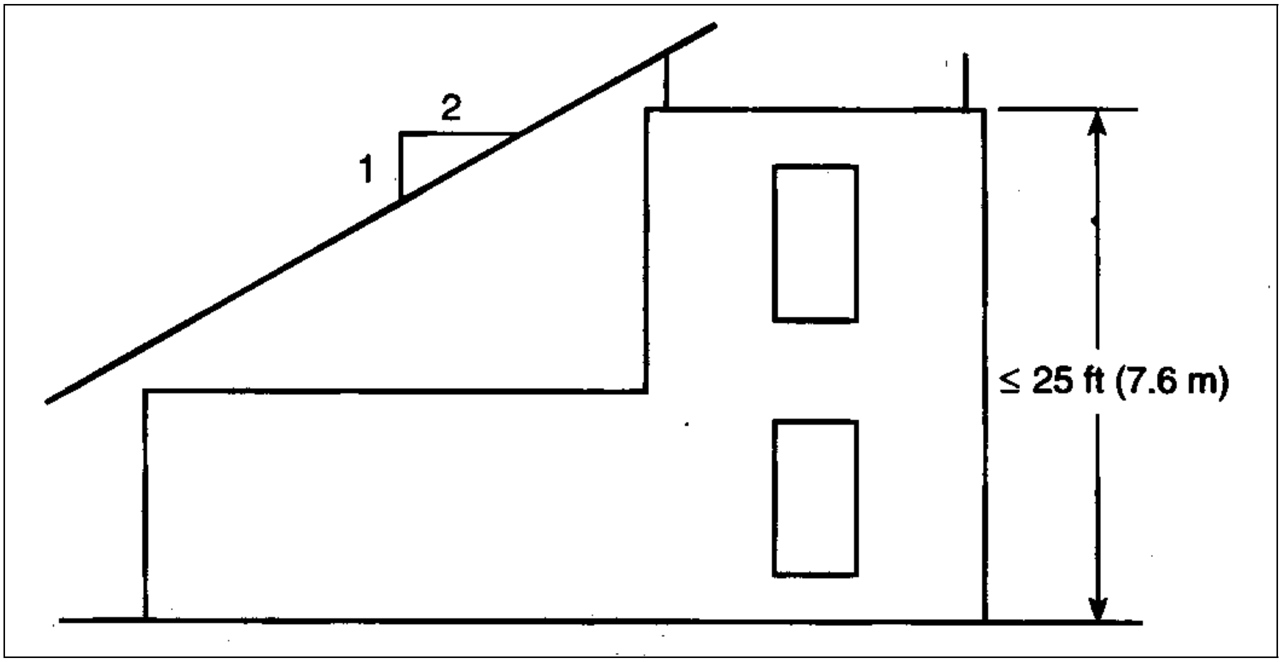

Figure 3-18. Lower roof protection for flat roof 25-feet or less high

(j) Structures that do not exceed 150-feet shall determine the zone of protection by the space not intruded by a rolling sphere having a radius of 150-feet (46 meters). When the sphere is tangent to earth and resting against an air terminal, all space in the vertical plane between the two points of contact and under the sphere are in the zone of protection. A zone of protection is also formed when such a sphere is resting on two or more air terminals. This zone shall also include the vertical plane under the sphere and between those devices, as shown in figure 3-13. All possible placements of the sphere must be considered when determining the zone of protection using the rolling sphere model.

(k) Structures greater than 150-feet (46 meters) above earth or above a lower air terminal shall determine the zone of protection to be the space in the vertical plane between points of contact and under the sphere when the sphere is resting against a vertical surface of the structure and the lower air terminal or earth. The zone of protection shall be limited to the space above the horizontal plane of the lowest air terminal unless it can be extended by further analysis, such as in rolling the sphere to be tangent to earth.

(2) To provide effective protection, it is of utmost importance that a low-impedance path to ground exists. This applies to all components and connections from the air terminals to the grounding electrodes.

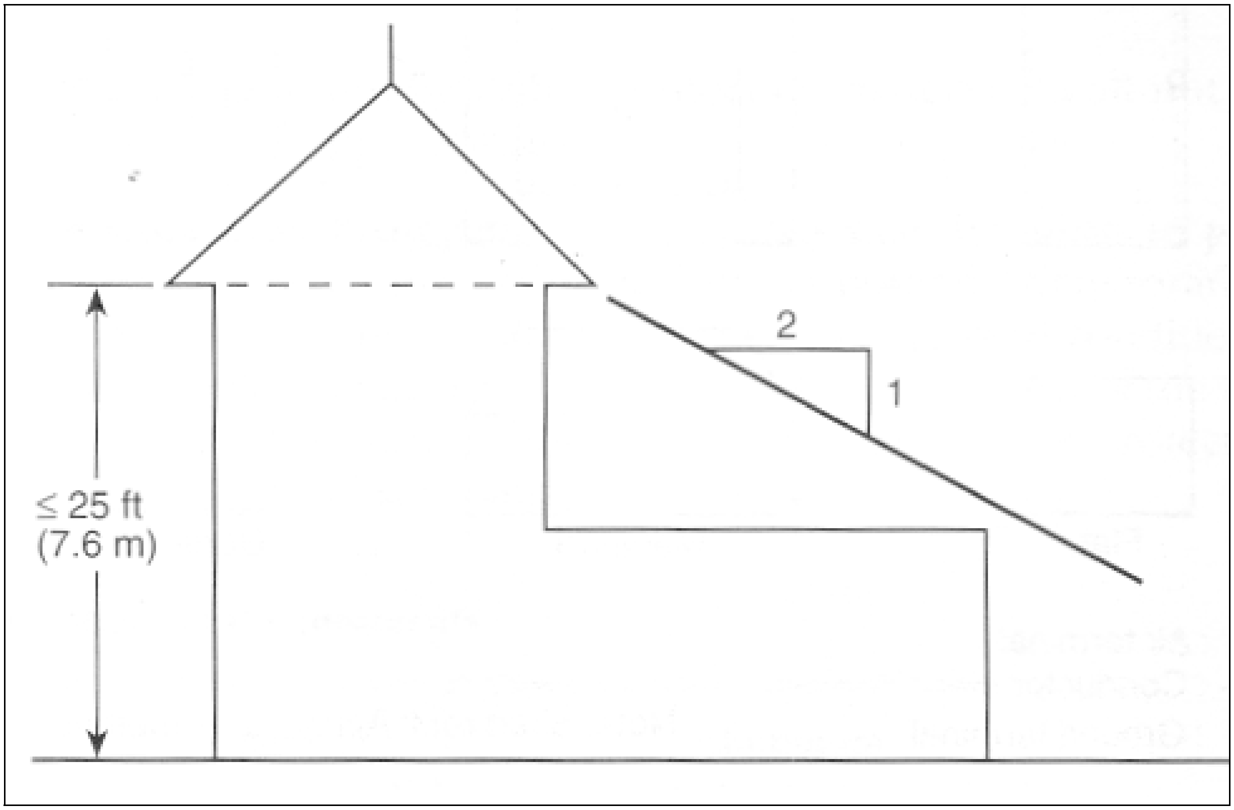

Figure 3-19. Lower roof protection provided by pitched roof 25-feet or less high

Low impedance is essential so that the huge currents involved will follow the design path in preference to alternative paths offered by building materials such as wood, brick, tile, stone, or concrete. When lightning follows these higher impedance paths, extensive damage may be caused by the heat and mechanical forces generated during the passage of the lightning discharge. A low-impedance path reduces the potential difference between the storm system, the earth, and the protection to the point where a stroke does not occur or at least is somewhat controlled. Even with installations built on solid rock, an extensive low-impedance ground electrode/system is required, as well as solid connections between components and earth. Standards do not call out a specific ohmic ground value; however, every effort must be made to obtain the lowest value possible. The down conductors from the air terminals to the earth connections provide this low impedance path.

(a) Install roof and down conductors so that they offer the least possible impedance to the passage of stroke currents between the air terminals and the earth. The most direct path is the best. The radius of conductor bends shall not be less than 8 inches nor shall the angle of such bends be less than 90 degrees.

(b) Course down conductors over the extreme outer portions of the structure and separate them as far apart as possible. Preferred locations are at diagonally opposite corners on square or rectangular structures and symmetrically distributed around cylindrical structures.

(c) Locate down conductors as close as practical to air terminals and to the most convenient places for attaching the conductors to the earth electrode subsystem of the structure. The down conductors should be equally and symmetrically spaced about the perimeter of the structure.

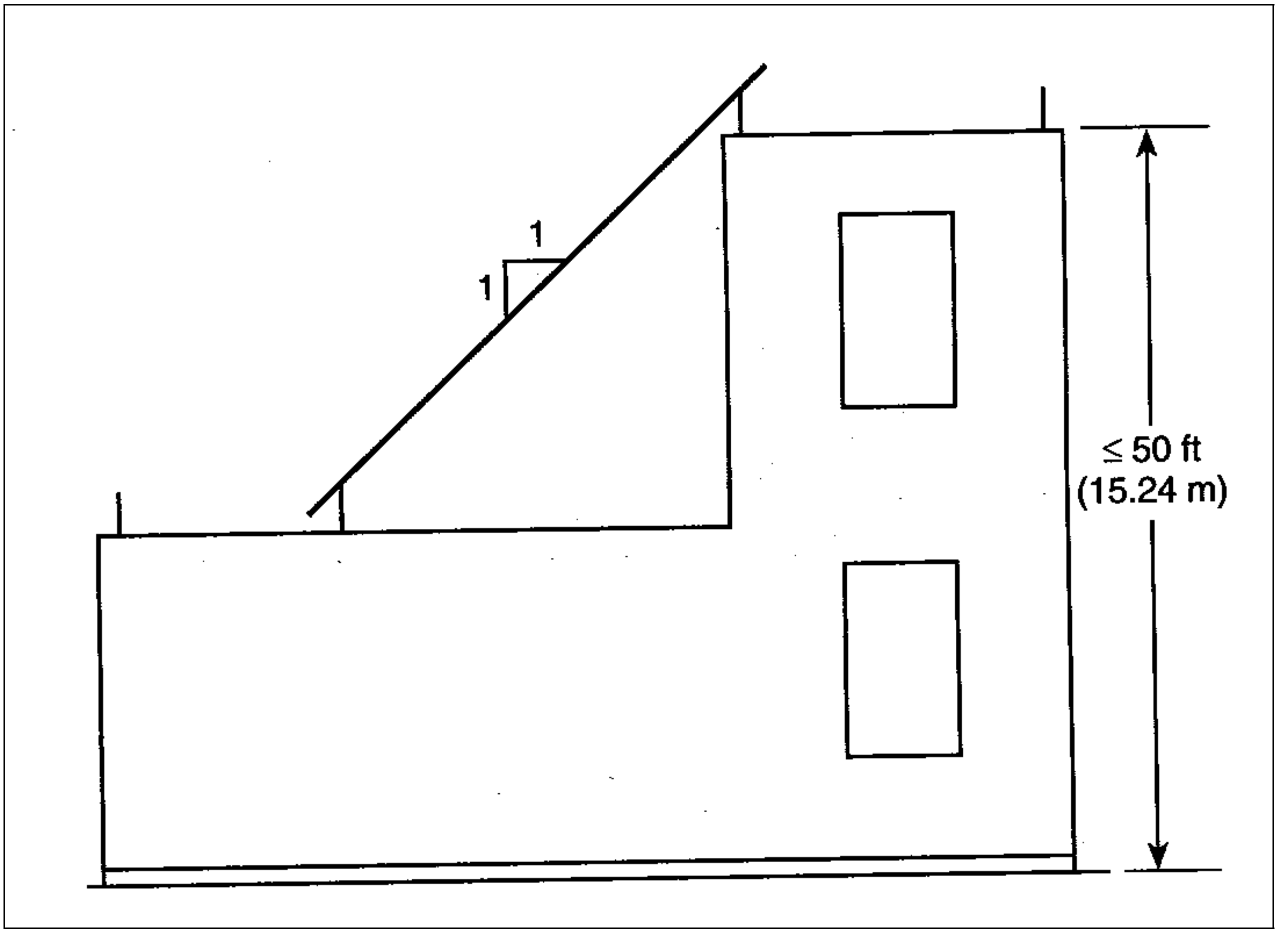

Figure 3-20. Lower roof protection for flat roof 50-feet or less high

(d) At least two down conductors are required on all structures except on slender objects like flagpoles, antenna masts (not substantial towers), light poles, and the like.

(e) Provide one additional down conductor for each additional 30 meters (100 feet) or fraction thereof on structures having a perimeter exceeding 75 meters (250 feet). On structures having flat or gently sloping roofs and on irregular-shaped structures, the number of down conductors should be such that the length of the average roof conductor joining them does not exceed 30 meters (100 feet). The spacing between down conductors need not be less than 15 meters (50 feet).

(*f)* Down conductors are to be provided or located appropriately to avoid dead ends in excess of 4.8 meters (16 feet) in length. See figure 3-22, note 1.

(g) Maintain down conductors in a downward course with routing around or through any obstruction which may lie in the path. Sharp bends or turns are to be avoided with necessary turns limited to not less than 90 degrees and not less than 20 cm (8 inches) in radius.

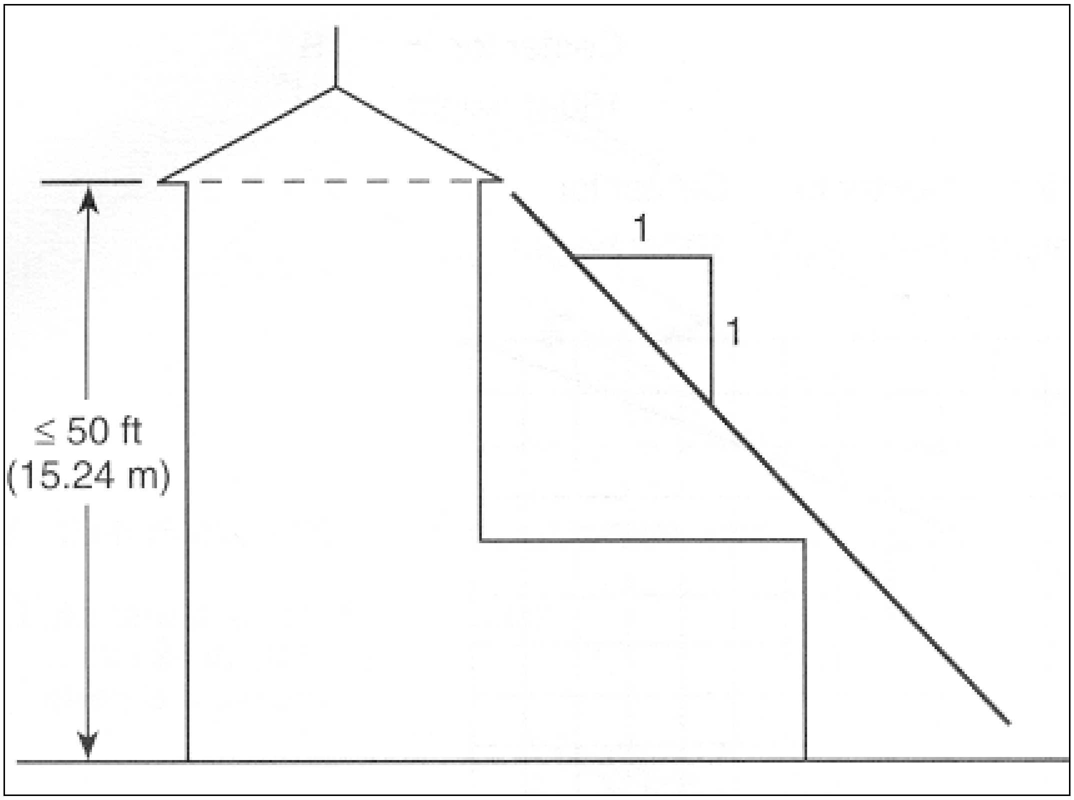

Figure 3-21. Lower roof protection for pitched roof 50-feet or less high

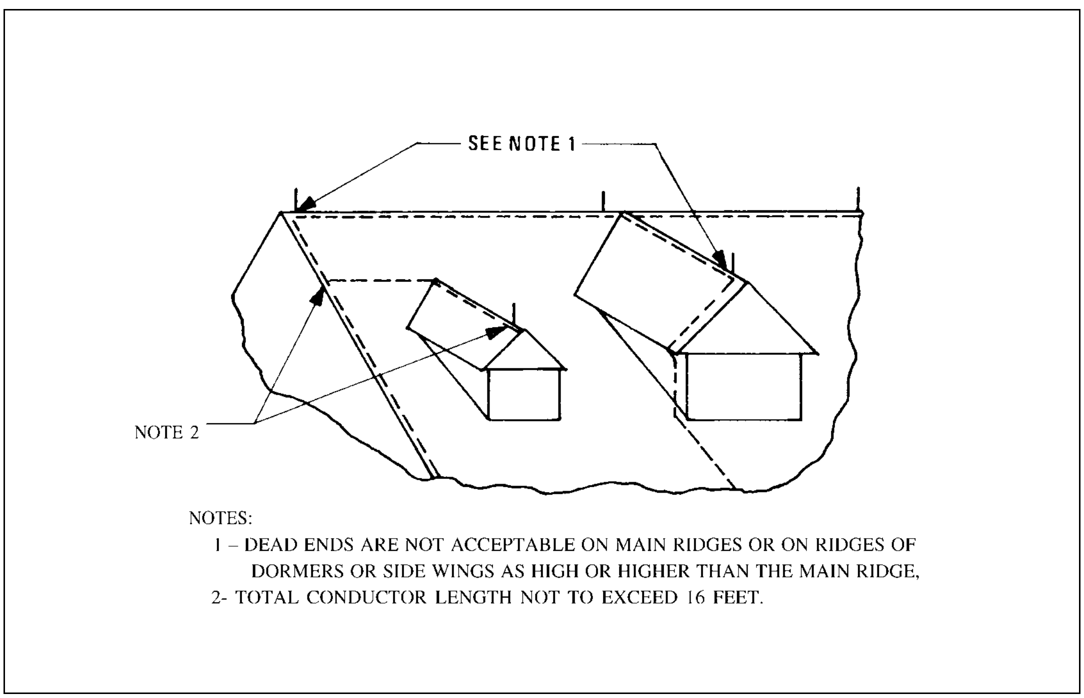

Figure 3-22. Criteria for dead end coverage

(h) Where large re-entrant loops (i.e., those with greater than 90-degree turns) cannot be avoided, e.g., around cornices or over parapets, the conductor should be routed to ensure that the open side of the loop is greater than one-eighth the length of the remaining sides of the loop. It is advised, however, to course the conductor through holes or troughs through the obstacles and avoid the loop completely whenever possible.

(i) On structures with overhangs such as antenna towers with extended platforms or buildings utilizing cantilevered construction, run the down conductors vertically through the interior of the structure. Internally routed conductors must be enclosed in non-metallic, non-combustible ducts.

(j) Substantial metal structural elements of buildings may be substituted for regular lightning conductors where, inherently or by suitable electrical bonding, they are electrically continuous from the air terminal to the earth electrode connection. The structural elements must have a conducting cross-sectional area, including that in joints, at least twice that of the lightning conductor that would otherwise be used. There need be no difference whether such conductors are on the interior or exterior of the structure when used for down conductors. Steel frame buildings encased in bricks or other masonry products must have external air terminals and roof conductors installed and bonded directly to the structural members to keep the lightning discharge from having to penetrate the masonry shell to reach the frame members.

(3) Provide each air terminal with a two-way path to earth through the installation of roof and down conductors conforming to table 3-3 for structures not greater than 75 feet in height and conforming to table 3-4 for structures greater than 75 feet in height. An exception is that air terminals located on prominent dormers extending less than 16 feet from the main structure need have only one connecting path from the terminal to the main down conductor.

Table 3-3. Minimum requirements for roof and down conductors on structures not greater than 75 feet (23 meters) in height

Conductor		**Material**	
		Copper	**Aluminum**
Cable	Strand Size	14 AWG	12 AWG
	Wt/1000 ft.	187 ½ lbs	95 lbs
	Area	59,500 Cir Roils	98,500 Cir Roils
	dc Resistance	.176 ohms/1000 ft.	.176 ohms/1000 ft.
Solid Strip	Thickness	14 AWG	12 AWG
	Width	1 in.	1 in.
	dc Resistance	.176 ohms/1000 ft.	.176 ohms/1000 ft.
Solid Rod	Wt/1000 ft.	186 ½ lbs	95 lbs
	dc Resistance	.176 ohms/1000 ft.	.176 ohms/1000 ft.
Tubular Rod	Wt/1000 ft.	187 ½ lbs	95 lbs
	Wall Thickness	.032 in.	.064 in.
	dc Resistance	.176 ohms/1000 ft.	.176 ohms/1000 ft.

Table 3-4. Minimum requirements for roof and down conductors on structures greater than 75 feet (23 meters) in height

Material	Strand Size	Weight/ft.	Weight/1000 ft.	dc Resistance/1000 ft.
Copper	14 AWG	6 oz	375 lbs	.088 ohms
Aluminum	12 AWG	3 oz	190 lbs	.088 ohms

(a) Roof conductors should be routed along ridges of gable, gambrel, and hip roofs, and around the perimeter of flat and gently sloping roofs.

(b) Roof grounding conductors routed throughout decks, flat surfaces, and flat roofs should be interconnected to form closed loops to insure that all air terminals have at least two paths to earth.

(c) Ridge conductors may drop from a higher to a lower roof level without installing an extra down lead at the point of intersection of the two roof levels if there are not more than two air terminals on the lower roof level.

(d) On roofs that exceed 50 feet in width, additional conductors are to be provided to interconnect the air terminals required to protect large flat areas. One additional conductor for each 50 feet in width is necessary. For example, on roofs 50 to 100 feet wide, add one additional run; on roofs 100 to 150 feet wide, add two additional runs; etc. These additional runs must be interconnected together and to the perimeter conductor at 150-foot intervals with cross conductors as illustrated in figure 3-17.

(e) Maintain a horizontal or downward course with roof conductors. Provide "U" or "V" (up and down) pockets with a down conductor from the base of the pocket to ground or to a convenient lead of the main down conductor.

(f) Route conductors through or around obstructions which lie in a horizontal plane with the conductor [figure 3-23(b) and (c)]. Bends in the conductor should not include an angle of less than 90 degrees and should maintain a radius of 8 inches or greater [figure 3-23(d)]. In particular, re-entrant loops should be avoided. When routing around obstructions, wide gradual bends are preferred. Other recommended practices are illustrated in figure 3-23(e) through (h).

(g) Securely attach the conductors directly to the ridge roll or roof with UL-approved fasteners every 3 feet.

(h) Conductors may be coursed through air up to 0.9 meters (3 feet) without support. With an acceptable support such as a 1.9 cm (3/4-inch) copper-clad ground rod or its equivalent, securely fastened at each end, a conductor may be coursed up to 1.8 meters (6 feet) through air.

(4) To complete the conventional lightning-protection system installation, all metallic elements (roof fans, vents, etc.), grounded or isolated, which are located on the roof or in the exterior walls near the down conductors, must be bonded to the down conductors because the possibility of a sideflash exists. A sideflash is an arc caused by a difference in potential between a down conductor and a metallic element. The bonding eliminates potential difference and prevents high current flow from damaging these components.

(5) Continuous conductor runs shall be used if at all possible. Connections and splices shall be of high quality and performed using approved manufacturer's recommended methods and tools. Figure 3-23 shows several examples of splices and connections.

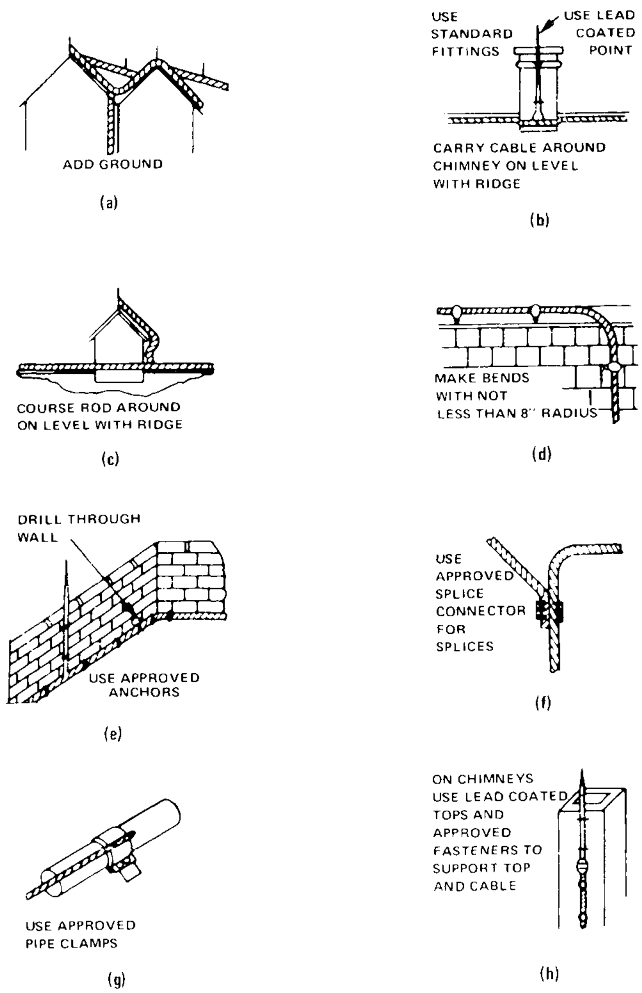

Figure 3-23. Recommended construction practices for integral lightning protection systems

(6) Securely attach air terminals and roof and down conductors to the building or other object upon which they are placed. Fasteners (including nails, screws, or other means by which they are attached) should be substantial in construction, not subject to breakage, and should be of the same material as the conductor or of a material that will preclude serious tendency towards electrolytic corrosion in the presence of moisture because of contact between the different metals. Keep all hardware, component parts, and joints that are not welded or brazed and that require inspection for maintenance and repair readily accessible. Any special fixtures required for access should be permanently attached to prevent loss. However, appropriate locks or other devices essential to safety, security, and physical protection of the hardware or of the area in which it is located may be used.

(7) No part of the structure being protected should extend outside the protected zone. Where it is impractical to provide a common mast to provide protection for an entire structure, additional masts should be provided. If the pole is made of a non-conducting material, provide an air terminal extending not less than 0.6 meters (2 feet) nor more than 0.9 meters (3 feet) above the top of the pole. Connect the base of the mast (if metal) or the down conductors to the earth electrode subsystem of the protected structure with at least a No. 6 AWG copper conductor or equivalent.

(8) If the poles are of a non-conducting material, an air terminal shall be securely mounted on the top of each pole, extending not less than 0.45 meters (1.5 feet) above the top of the pole. Down conductors are run down the side of the pole or the guy wire may be employed as the conductor as shown in figure 3-24. If the guy wire is used, it shall be properly grounded and bonded and both this wire and the overhead ground wire are dead-ended at the pole. The overhead ground wire and the guy wire shall be interconnected with a separate cable. Down conductors and guy wires used as down conductors are to

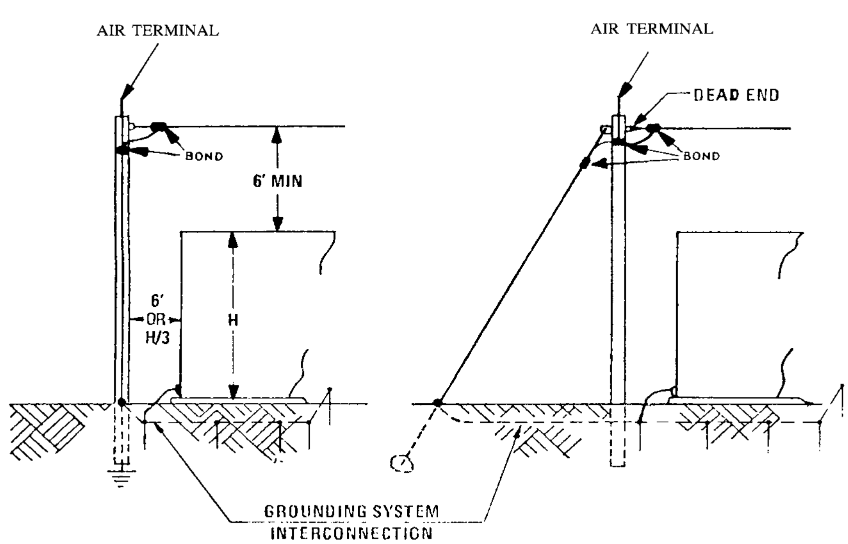

Figure 3-24. Overhead ground wire lightning protection system

be connected to the earth electrode subsystem of the structure being protected. Guy wires not located near existing earth electrode subsystems shall be grounded either to their respective ground anchor (by use of an interconnecting cable) or to a separate ground rod.

(a) The height of the poles should be sufficient to provide a clearance of not less than 1.8 meters (6 feet) between the overhead ground wire and the highest projection on the building. When the overhead ground wire system is used to protect stacks or vents which emit explosive dusts, vapors, or gases under forced draft, the cable is installed so that it has a clearance of at least 4.5 meters (15 feet) above the object receiving protection.

(b) With either the mast type or the overhead ground wire type of system, the pole is placed at a distance from the structure that is at least one-third the height of the structure, but in no instance less than 1.8 meters (6 feet).

d. Transient protection. An essential addition to the air terminals, down conductors, and earth connection for the protection of electrical and electronic equipment is the installation of lightning arresters and terminal protection devices (TPDs) on all external power, communications, data, and control lines that penetrate the facility boundary. TPDs are fast-response protection devices installed for the purpose of shunting extraneous pulses to ground. Examples of commonly used terminal protection devices are carbon blocks, gas-filled spark gaps, zener diodes, and EMI power and signal line filters. These surge arresters and TPDs must respond in a sufficiently short time to limit the surge voltages produced by the lightning discharge to levels which can be tolerated by the equipment inside the facility. To obtain least response time and to limit the overshoot voltage of the arresters and TPDs, these devices must be properly grounded. They must be installed such that their leads are kept to minimum lengths and kept very near to facility ground conductors.

(1) Installation of a properly selected secondary ac surge arrester at the facility main service disconnect provides the best method for ensuring that high energy transients are not coupled to equipment by ac distribution lines within the facility. The surge arrester installed must have certain characteristics to ensure adequate protection.

(a) The arrester must be capable of safely dissipating transients of amplitudes and waveforms expected at the facility for a predetermined period of time. Selection of an arrester that will provide protection for a period of ten years is recommended.

(b) Have a turn-on time fast enough to ensure that transient energy will not cause damage before the surge arrester turns on and clamps. (50-5000 nanoseconds)

(c) Maintain a low enough discharge (clamp) voltage while dissipating transient current to prevent damage to protected equipment. (1.5 times system normal voltage)

(d) Have a reverse standoff voltage high enough to ensure non-conduction during normal operation. (1.75 time normal system voltage)

(e) Be capable of complete extinguishing after firing on an energized line.

(f) The surge arrester must be properly installed to ensure optimum operation. The input to each phase arrester contained in the surge arrester should be fused to provide protection against overload of, or damage to, the ac supply in the event an arrester should short. Also, indicator lights and an audible alarm that go off when a fuse opens should be provided on the front of the surge arrester enclosure as a maintenance aid.

(g) Proper installation of the surge arrester is of vital importance for optimum operation. A surge arrester with excellent operating characteristics cannot function properly if correct installation procedures are not used. All surge arresters should be installed in accordance with the manufacturer's recommendations.

(h) If possible, install arresters inside the first service disconnect box to keep interconnecting lead lengths as short as feasible. Use interconnecting wire of sufficient size to limit resistance and inductance in the transient path to ground through the surge arrester. Interconnecting wiring should be routed as straight and direct as possible with no sharp bends and the least number of bends possible. Do not include loops in the wiring. The arrester must be grounded by the shortest low impedance path available.

(i) Installation of surge arresters is shown for grounded and ungrounded service in figures 3-25 and 3-26 respectively. For best possible protection, the line supply side of the main service disconnect means should be connected to the phase input(s) of the surge arrester. However, when necessary to facilitate removal of ac power for surge arrester maintenance, it is permissible to connect the surge arrester to the load side of the main service disconnect means. In order to prevent introducing excessive inductance and resistance in the transient path to the surge arrester, No. 4 AWG (minimum) insulated stranded copper wire of the minimum feasible length must be used to make the interconnection(s) unless otherwise recommended and guaranteed by the manufacturer. Also, the interconnecting wiring must not contain loops or sharp bends. Otherwise, the response time of the surge arrester will be delayed and a higher clamp voltage than that of the surge arrester will be impressed across the protected equipment, thus increasing the possibility of damage. In the event a very fast transient should occur, it is quite likely that the surge arrester would never turn on, and all of the transient energy would be dissipated by supposedly protected equipment.

(j) When the surge arrester is not properly grounded, its response time will be delayed and a higher clamp voltage than that of the surge arrester will be impressed across the equipment being protected. This can also be expected if the earth ground connection for the surge arrester contains loops or sharp bends or is not properly bonded to the earth electrode subsystem. To overcome this problem, stranded copper wire specified in accordance with Article 280 of the *NEC*® must be used to make the ground connection unless other specifications are provided by the manufacturer of the surge arresters. Figures 3-25 and 3-26 show the surge arresters installed to ensure the best direct route to ground thereby minimizing the lead inductance(s) and ensure the firing of the surge arresters. For best results exothermic welds should be used for bonding to the earth electrode subsystem. UL–approved pressure connectors are suitable for aboveground bonds.

(k) Selection of a surge arrester that will provide adequate protection against worst case transients is recommended.

(l) Several surge arrester application guide standards are available from the IEEE to aid in the selection of surge arresters for specific applications. These standards are IEEE C62.2, Guide for the Application of Gapped Silicon-Carbide Surge Arresters for AC Systems; IEEE C62.22, Guide for the Application of Metal-Oxide Surge Arresters for AC Systems; IEEE C62.22.1, Guide for the Connection of Surge Arresters to Protect Insulated, Shielded Electric Power Cable Systems; IEEE C62.37.1, Guide for the Application of Thyristor Surge Protective Devices; IEEE C62.42 Guide for the Application of Gas Tube and Air Gap Arrester Low-Voltage (Equal to or Less Than 1000 Vrms or 1200Vdc) Surge Protective Devices; and IEEE C62.43, Guide for the Application of Surge Protectors Used in Low-Voltage (Equal to or Less Than 1000 Vrms or 1200Vdc) Data, Communications, and Signaling Circuits.

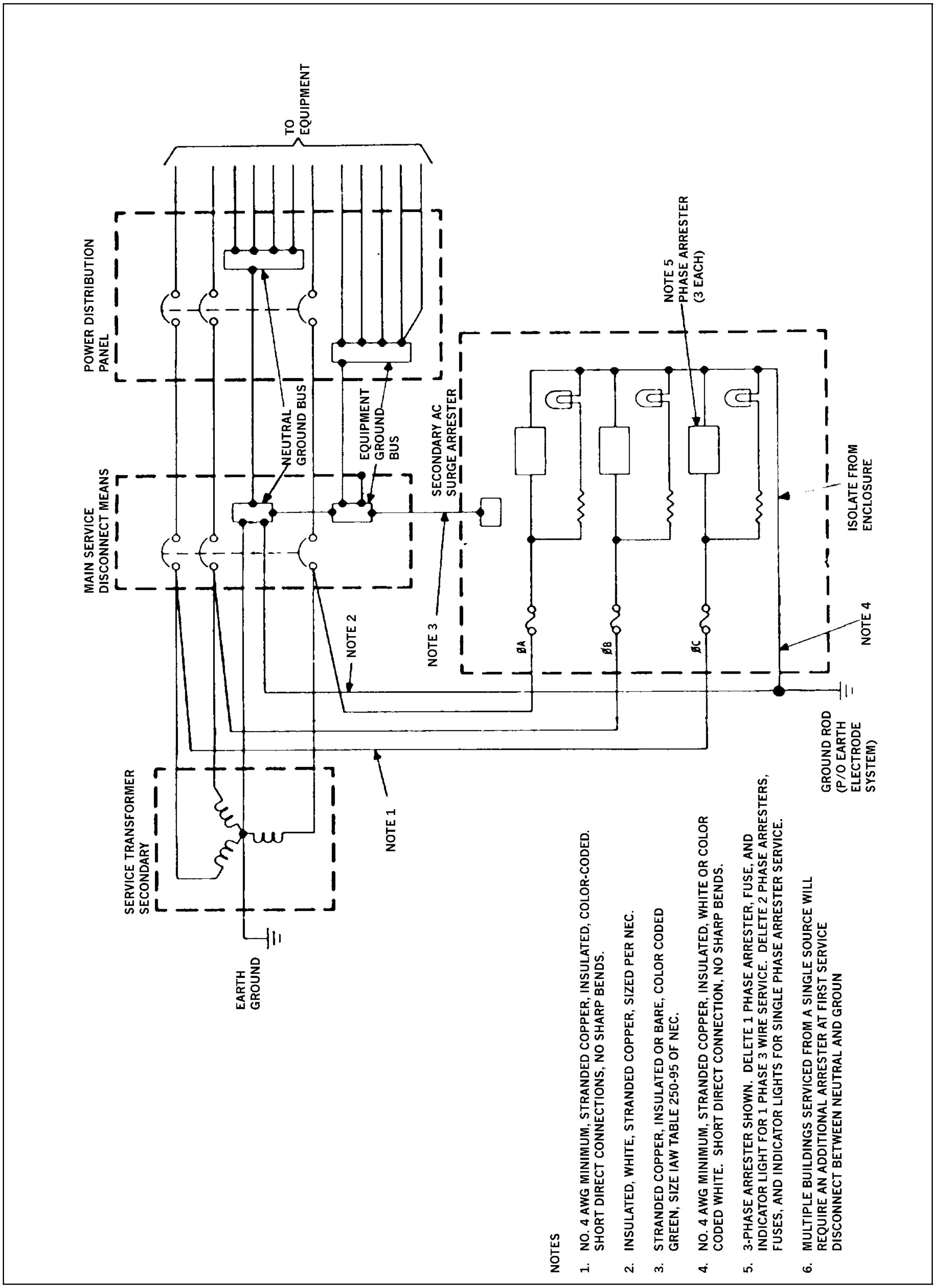

Figure 3-25. Secondary ac surge arrester installation, grounded service

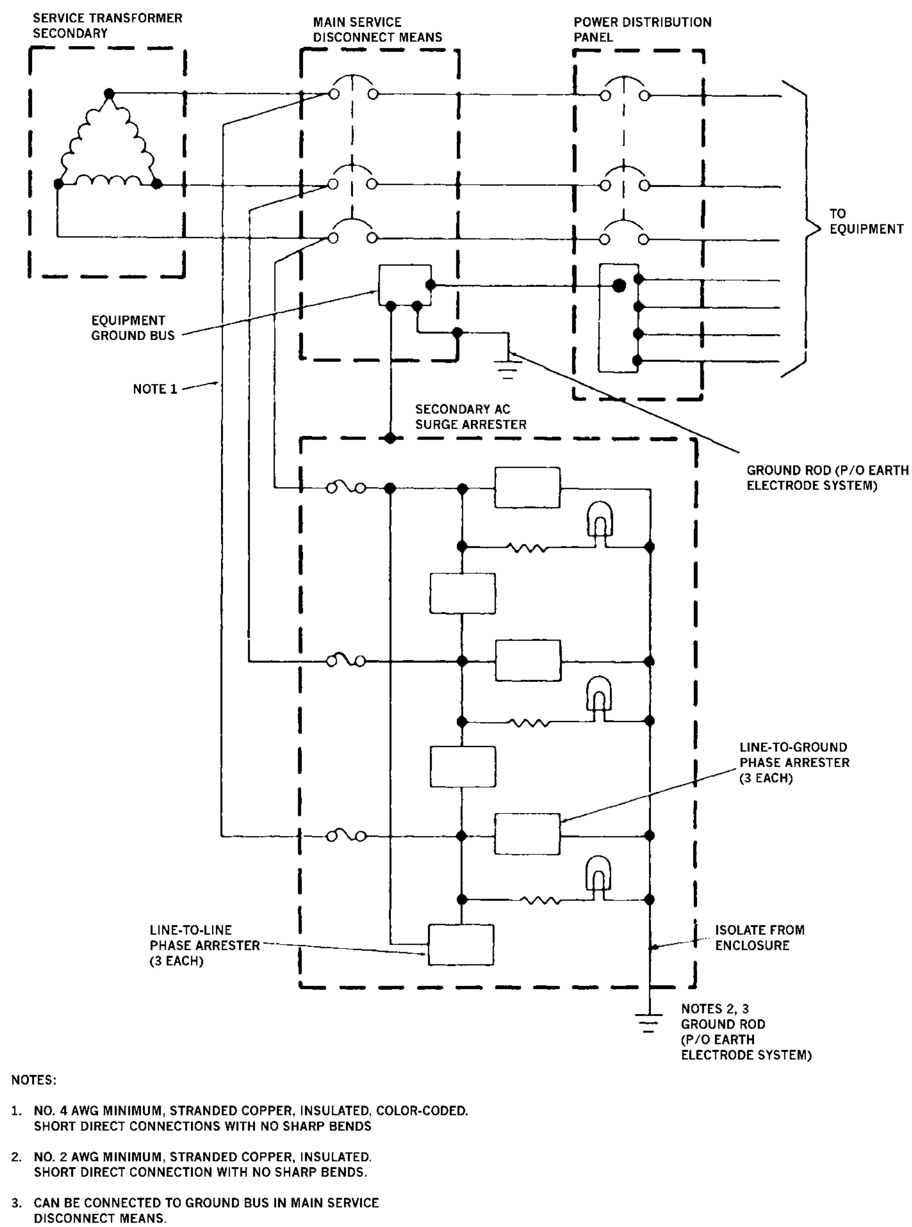

Figure 3-26. Secondary ac surge arrester installation, ungrounded service

(m) The turn-on time (response time) is the time required for an arrester to turn on and clamp a transient after turn-on voltage is impressed across device terminals. All basic suppressor devices used in the manufacture of surge arresters are voltage dependent for ionization, breakdown, and other phenomena associated with breakdown. Therefore, a low turn-on voltage enhances a faster turn-on time. Turn-on time requirements for a surge arrester must be directly related to the withstand level for equipment and components being protected. For instance, if only heavy duty electrical equipment, such as motors, contactors, and switches are being protected, relatively slow turn-on of 1 to 5 microseconds can be tolerated. However, if solid-state electronic equipment, or a combination of electrical and electronic solid-state equipment is being protected, turn-on time becomes much more critical. In general, the most rapid response time available is desirable. However, cost and current dissipation capability normally place constraints on such selection criteria. Four types of arresters are currently manufactured. Their general characteristics are listed in table 3-5.

(n) Turn-on time of 50 nanoseconds is sufficiently fast to protect all except very critical components that would directly receive transient energy prior to turn-on and clamp of the surge arrester. Solid-state units may be used for protection of very critical equipment components, and the gas-filled spark gap type will provide adequate protection for heavy duty electrical equipment such as motors, contactors, and switches. However, arresters with slow turn-on time and high turn-on voltage should not be used to protect electronic equipment that has low-voltage, fast turn-on transient suppression devices, or circuits included as an integral part of the equipment. Otherwise, the transient suppression in the equipment will turn on and attempt to dissipate transient energy before the surge arrester installed at the main service disconnect means turns on. In most cases, this will rapidly destroy equipment-level transient suppression. The resistance and inductance of power distribution panels and power distribution wiring within the facility will tend to slow down transient rise time and also dissipate some transient energy both before and after the surge arrester turns on. The resistance and inductance works in conjunction with the surge arrester at the main service disconnect means to provide additional protection. However, the true degree of protection thus provided varies widely due to varying transient waveforms, and size and length of distribution wiring within the facility.

Table 3-5. Generalized characteristics for surge arresters by type

Type	Turn-on Time	Current Capacity	Firing/Clamp Voltage	Reverse Standoff Voltage	Cost
Gas-filled spark gap	5 – 250 nanoseconds for 10 kV/micro sec rise time	Up to 150,000 amperes Life = 2500 surges @ 10,00 amperes	350 – 5500 volts	200-300%	\$25 - \$750
MOV or ZNR	50 nanoseconds, any rise time	Varies	300 – 3000 volts	175±25%	\$50 - \$1000
Solid-State	10 nanoseconds, any rise time	Varies usually 50 – 100 amperes	275 – 750 volts	175±25%	\$100 – \$25,000

(o) Design of effective lightning transient protection requires that the surge arrester turn on very rapidly at the lowest voltage possible when a transient occurs. In addition, it is desirable that a low clamp voltage be maintained across the surge arrester while conducting surge current to ground. Turn-on

voltage and associated turn-on time as well as clamp voltage are proportional to reverse standoff voltage. That is, an arrester with a low reverse standoff voltage has a lower turn-on voltage (and thus a faster turn-on time) and a lower clamp voltage than an arrester with a higher reverse standoff voltage. Therefore, it is important that the surge arrester has the lowest possible reverse standoff voltage.

(p) For effective protection, the reverse standoff voltage should be between 200 to 300 percent of nominal line-to-ground voltage of the appropriate ac service lines for a spark gap type surge arrester that is to be installed line to ground. The reverse standoff voltage should also be between 200 to 300 percent of nominal line-to-line voltage of appropriate ac service lines for a spark gap type surge arrester that is to be installed line to line. The reverse standoff voltage for metal oxide varistor (MOV) and zinc oxide non-linear resistor (ZNR) type arresters should be 175 ± 25 percent of the nominal line-to-ground or line-to-line voltages of the appropriate ac service lines.

(2) Electrical and electronic equipment at various facilities has been severely damaged by lightning-generated transients. The transients occur on externally exposed lines that directly interface equipment. Externally exposed lines are outside lines, buried, overhead, etc., that are exposed to weather elements. The lines include incoming ac service conductors, equipment signal, status, control, grounding conductors, and intrafacility ac and dc power lines. This section identifies transient source and damage, waveforms and amplitudes of projected transients on different types of lines, frequency of transient occurrence, and effective methods to implement to preclude equipment damage and operational upset when transients occur.

(a) Electrical and electronic equipment comprising an operating system is susceptible to damage from lightning-generated transient surges via two primary sources - transient surges coupled to equipment from incoming commercial ac power conductors and transient surges coupled to equipment by connected facility control, status, power, ground, and data and signal lines that originate or terminate at equipment located externally to the building or structure housing the equipment of interest.

(b) Damage resulting from lightning-generated transients occurs in many forms. Entire equipment chassis have been exploded and burned, and wall-mounted equipment has been blown off the wall by large-magnitude transient energy. Damage usually consists of catastrophic component failure or shortened operating lifetime of components resulting from over-stress.

(c) Damage can be minimized, and in most instances eliminated, by properly using the generally field-proven protection methods. In order to be cost effective and to provide effective protection, allocation of protection must be divided into three general categories: (1) transient suppression (metal conduit and guard wires) for outside lines that interface equipment to be protected; (2) installation of transient suppression devices on both ends of exterior lines immediately after equipment building penetration or at exterior equipment termination, and on incoming ac service entrance lines at the facility main service disconnect means (on shielded facilities, transient suppression devices (TSDs) should be installed in an entry vault or inside the main service disconnect box); and (3) including transient suppression as an integral part of protected equipment at the exterior line-equipment interfaces.

(3) If realistic transient protection is to be designed, frequency of transient occurrence, amplitudes and waveforms of transients, and the basic insulation level (BIL) of equipment to be protected must be defined. The BIL is the short-duration voltage and current surge levels that equipment can withstand without overstressing or immediate destruction of components occurring, and without equipment operational upset occurring.

(a) Integrated circuits, discrete transistors and diodes, capacitors, miniature relays, transformers, and switches used in the design of solid-state equipment are very susceptible to damage from lightning-

generated transient surges. Other components are not immune to damage but are susceptible to a much lesser degree. Standards do not exist for specifying the withstand level against lightning-transients for most equipment and components. Therefore, accurate information must be obtained from manufacturers, laboratory testing performed, or conservative engineering estimates made. Typical withstand level limits for common devices are shown in table 3-6.

Table 3-6. Typical withstand level limits for electrical devices

Device	Withstand Level Limit
Integrated circuits	1.5 times normal rated junction and Vcc voltage
Discrete transistors	2 times normal rated junction voltage
Diodes	1.5 times peak inverse voltage
Miniature relays, transformers, and switches	3 times rated voltage
Capacitors	1.5 times dc working voltage unless transient dielectric punch-through voltage known
DC power supplies with step-down transformer and diode bridge	1.5 times diode peak inverse voltage (PIV) rating times the transformer secondary to primary voltage ratio
Small motors, small transformer, and light machinery	10 times normal operating voltage
Large motors, large transformers, and heavy machinery	20 times normal operating voltage

e. Protection of conductors and other systems. Protection of outside distribution circuits and components from lightning strikes is described below. Because of the large physical size of incoming ac service conductors, less impedance (resistance and inductance) is presented to transient surge current flow. As a result, amplitude and waveforms of transients appearing at ac inputs are quite different from those appearing at control, status, data, signal, and in-system power-line inputs. Therefore, protection for incoming ac power service conductors is discussed separately from that for other externally exposed lines.

(1) An overhead guard wire has been proven to provide an effective level of protection for overhead service conductors against direct lightning strikes. This guard wire also provides a low level of protection against transients induced on lines by close proximity strikes as well as nearby cloud-to-cloud discharges. The guard wire must be located above and parallel to the service conductors. To be effective, the height of the guard wire must not allow a circle with the radius of 100-feet tangent to the guard wire and earth to touch the service conductors to be protected per NFPA 780. The guard wire must extend from the secondary of the service transformer for the facility to the facility service entrance fitting. Also, at each end the guard wire must extend to, and be bonded to, an effective earth ground or to the earth electrode subsystem of the facility. When the distance between the service transformer and the facility service entrance exceeds 250 feet, the guard wire shall also be bonded to a ground rod. Since the guard wire and the earth electrode subsystem are usually comprised of different metals, exothermic welding is recommended.

(2) Transient protection on ac service conductors is accomplished by use of the following.

(a) Installation of an ac surge arrester at the facility main service disconnect means.

(b) Including surge suppressors as an integral part of equipment at ac power inputs of each critical sub-panel of a facility.

(c) Installation of suitable lightning or surge arresters on the primary and secondary of the main station service transformer.

(3) Protection against direct lightning strikes for underground cables may be accomplished by use of the following.

(a) Completely enclose buried lines in ferrous metal, electrically continuous, watertight conduit. Protect against direct lightning strikes to buried cable by installing a guard wire above the cables or cable duct. A 1/0 AWG bare copper cable laid directly over the protected cables is recommended. At least 25.4 cm (10 inches) should be maintained between the protected cables and the guard wire. For a relatively narrow spread of the cables, 0.9 meters (3 feet) or less, or for a duct less than 0.9 meters (3 feet) wide, only one guard wire cable is necessary. For wider cable spreads or wider ducts, at least two 1/0 AWG cables should be provided as illustrated in figure 3-27. The guard wires should be spaced at least 30 cm (12 inches) apart and be not less than 30 cm (12 inches) nor more than 45 cm (18 inches) inside the outermost wires or the edges of the duct. To be effective, the guard wires must be bonded to the earth electrode subsystem at each terminating facility. Exothermic welds provide the most effective bonding. Since the guard wire and protected cables are embedded in the earth, the applicable zone of protection is not known.

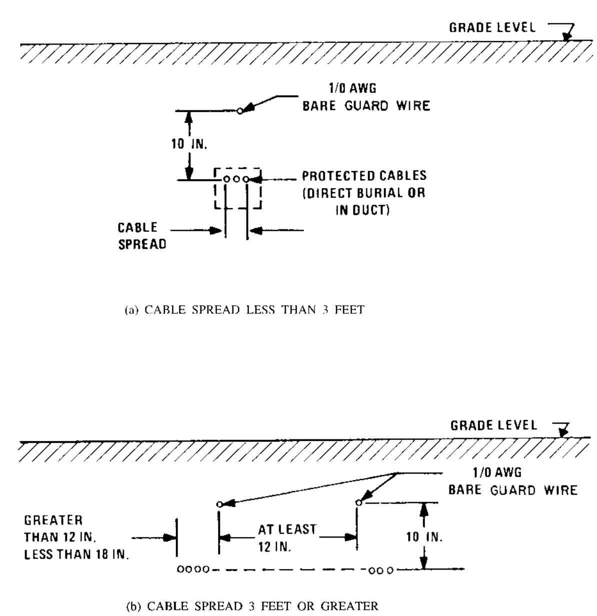

Figure 3-27. Lightning protection for underground cables

(b) Experimental use of a buried guard wire embedded in soil above and parallel to buried cable runs not enclosed in metal conduit has provided effective attenuation of lightning-induced transients. Use of the guard wire is recommended for protection of buried equipment lines not enclosed in metal conduit. Bare 1/0 AWG copper wire has provided the most effective protection during experimental use. The guard wire should be installed using the same guidelines given for underground cable runs encased in metal conduit.

(*4*) Waveguides between antennas and their associated transmit/receive equipment should be grounded in the following manner.

(a) Each waveguide shall be bonded to the down conductor of the air terminal at the top near the antenna and also at the bottom near the vertical to horizontal transition point. The waveguide shall also be bonded to the antenna tower at the same points as well as at an intermediate point if the tower exceeds 60 meters (200 feet).

(b) All waveguide support structures shall be bonded to the tower. The waveguide and supporting structure shall be bonded together at the waveguide entry plate and connected to the earth electrode subsystem.

(c) All waveguides, conduit, or piping entering a building shall be bonded to the waveguide entry plate, then to the earth electrode subsystem, as shown in figures 3-28 through 3-30.

(d) Rigid waveguides within 1.8 meters (6 feet) of each other should be bonded together through the entry plate or by means of a crimp type lug fastened under the waveguide flange bolts and No. 6 AWG wire. The bond shall be extended to the bus at the waveguide entry point and connected to the earth electrode system.

(e) Determine location of ground strap position and remove waveguide jacket. The ground strap is made from a piece of waveguide. Clean mating surfaces (waveguide and strap) with solvent or cleaning fluid.

(f) Wrap the strap with No. 14 AWG copper wire (for 8 GHz waveguide). For 4 GHz waveguide, use No. 10 AWG solid copper wire. Use adjustable stainless steel clamps as required to secure the strap. Tighten screw until the clamp grips firmly. Excessive tightening could damage the waveguide and impair the electrical characteristics. Weatherproof with Scotch Guard or equivalent and tape.

(g) An alternate method of securing the strap to the waveguide is to use wrap-around heat shrink to cover the bond and to maintain weatherproofing. Solder one end of a solid copper wire (#10 for 4 GHz and #14 for 8 GHz waveguide) to one end of corrugated portion of the ground strap. Align the corrugated section of the ground strap with the exposed section of the waveguide. Tightly wrap the wire around the ground strap and waveguide and solder the end of the wire to the ground strap for securing purposes. Apply the wrap-around heat shrink around the waveguide and heat according to the manufacturer's instructions.

(h) Remove all sharp and rough edges on ground strap.

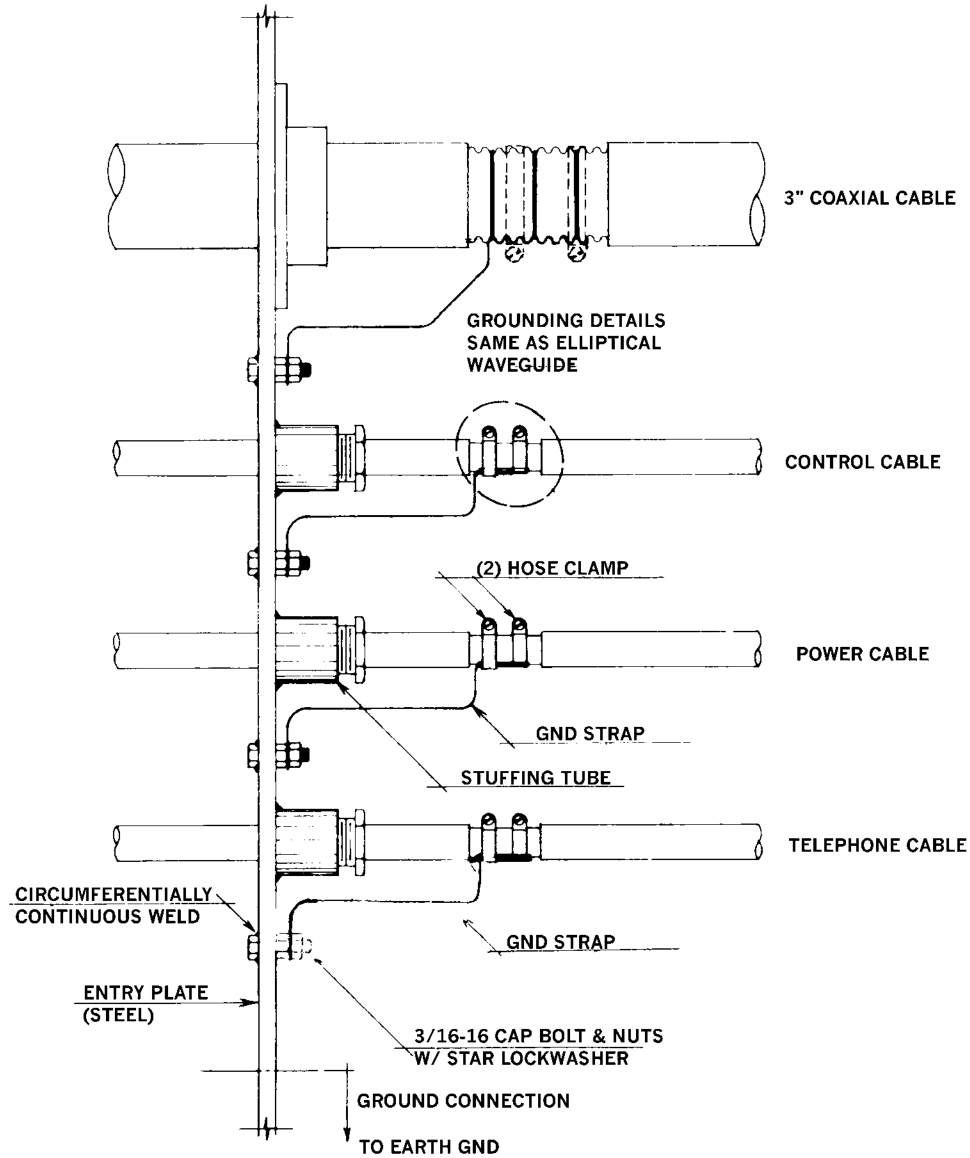

Figure 3-28. Communication cable entry installation

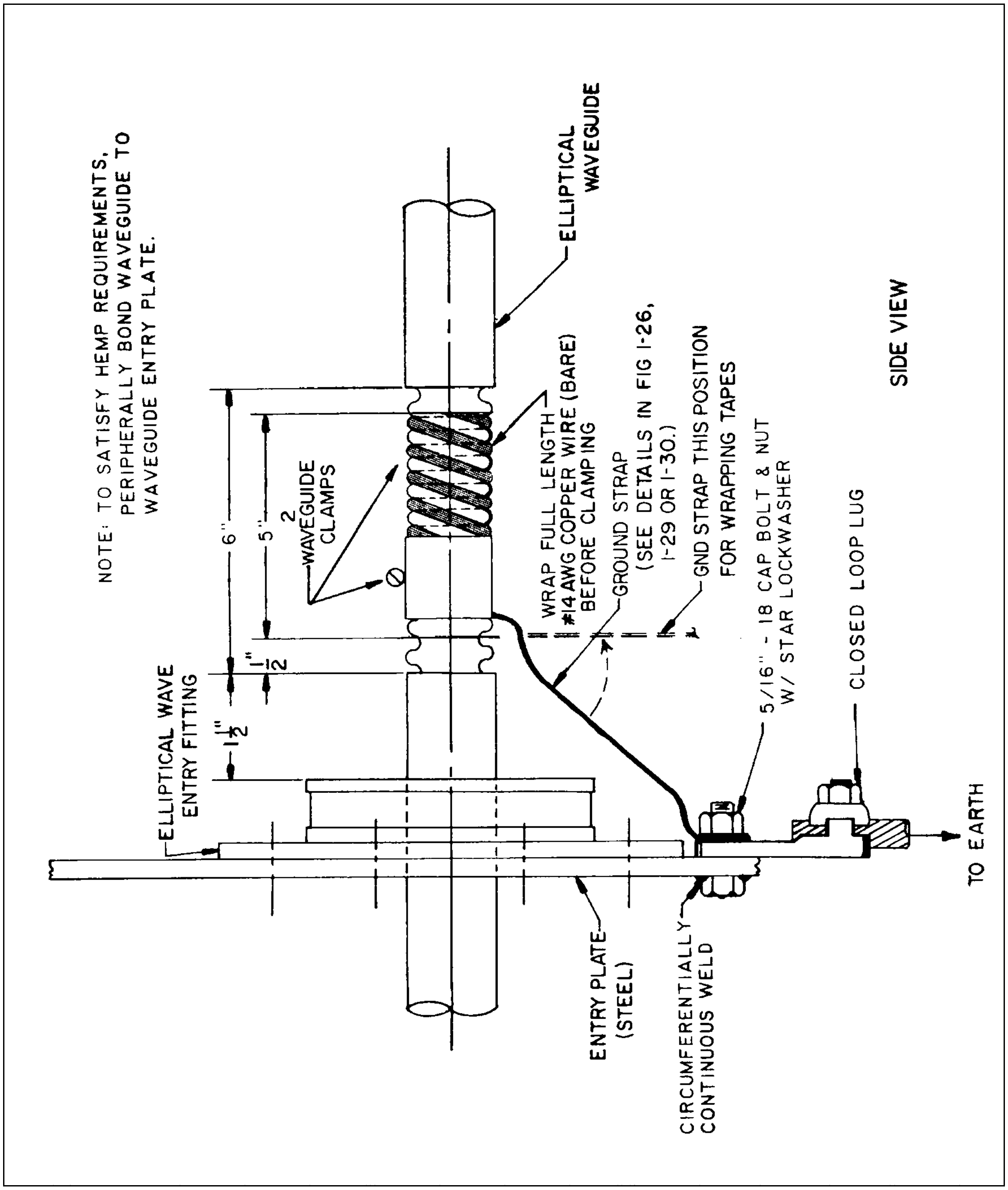

Figure 3-29. Grounding details for elliptical waveguide

f. Inspections. Inspections of the final installation shall be performed to confirm the system is installed in accordance with the engineering drawings and specifications. Inspections of the system should be implemented as integral elements of the facility during the construction of the building or structure. To ensure that the implementation is accomplished in a timely manner, the construction efforts should be carefully monitored. Prior to acceptance of the facility, the installation should be validated as acceptable using DA Form 7452-2-R shown in figure 3-31. The following guidelines are provided to aid in the inspection and checkout of the facility.

(1) The zone of protection established by the air terminals (or by the mast or overhead ground wire, if a separately installed system is provided) shall be determined. Locate air terminals on a scaled drawing of the structure (be sure to include all views). Verify all parts of the facility are adequately included within the zones of protection established by the air terminals. In deficient areas, determine what additional measures, if any, need to be taken.

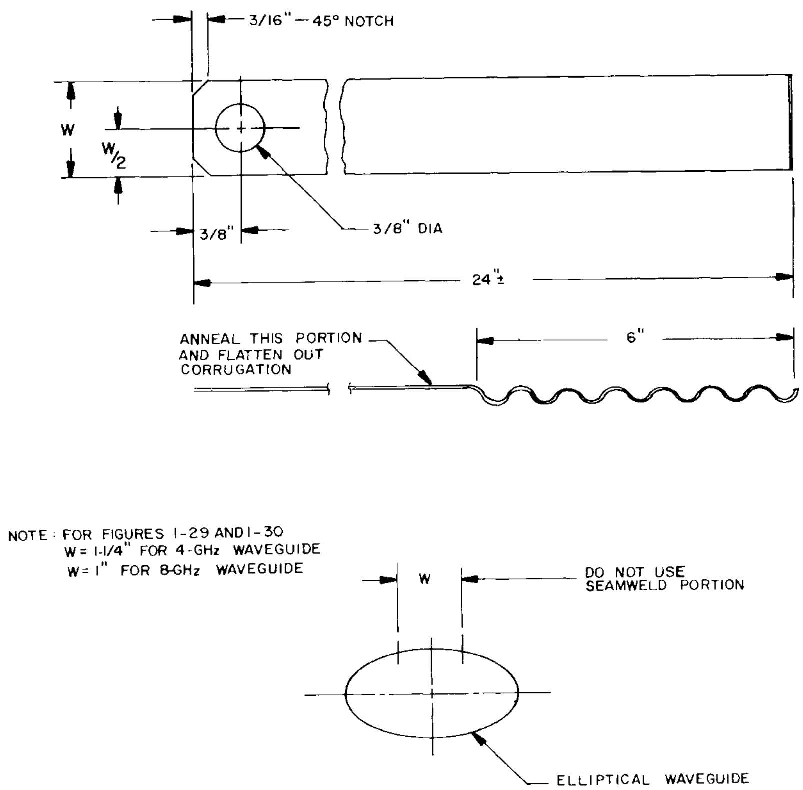

Figure 3-30. Ground strap fabrication details for elliptical waveguide

(2) Verify that the air terminals are the proper type, correct height, and in the proper locations.

(3) Verify roof conductors are the proper size and correct choice of materials.

(4) Verify the route of the roof conductors is acceptable and that all fasteners are acceptable.

(5) Verify down conductors are the proper size and correct material.

LIGHTNING PROTECTION GROUNDING SUBSYSTEM CHECKLIST FOR NEW FACILITIES
For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY Fort Tank	2. DATE *(YYYYMMDD)* 20020228
3. LOCATION Building 316	4. INSPECTOR Al Volta

5. SKETCH THE LAYOUT OF THE ACTUAL LIGHTNING PROTECTION SUBSYSTEM *(Or attach an up-to-date engineering drawing)*

See attached drawing 001-50-7, 30 November 2001 for details

6. ALL LIGHTNING PROTECTION EQUIPMENT UL LABELED: [X] YES [ ] NO

7. UL MASTER LABEL ISSUED AND PROPERLY ATTACHED TO THE BUILDING: [X] YES [ ] NO

8. AIR TERMINALS

8a. CLASS I	8b. HEIGHT 2 ft	8c. MATERIAL copper	8d. SIZE *(Diameter)* 5/8"
8e. PROPER BASES/FITTINGS [X] YES [ ] NO	8f. PHYSICAL CONDITION good	8g. PROPERLY INSTALLED [ ] YES [X] NO	8h. LOCATED AND SPACED AS SPECIFIED [X] YES [ ] NO

8i. DOES THE HEIGHT OF AIR TERMINALS PROVIDE PROPER CONE OF PROTECTION: [X] YES [ ] NO

8j. DEFICIENCIES: Need to reinstall properly

9. ROOF CONDUCTORS

9a. CLASS I	9b. TYPE stranded bare	9c. SIZE 1/2"	9d. MATERIAL copper
9e. BEND RADIOUS 10"	9f. SECURELY ANCHORED [X] YES [ ] NO	9g. PROPER FITTINGS [X] YES [ ] NO	9h. LOCATED AND SPACED AS SPECIFIED [X] YES [ ] NO

9i. PROPERLY BONDED TO AIR TERMINALS AND OTHER METAL OBJECTS ON ROOF: [X] YES [ ] NO

9j. PROPERLY INTERCONNECTED TO OTHER CROSS ROOF CONDUCTORS: [X] YES [ ] NO

9k. DEFICIENCIES: none

10. DOWN CONDUCTORS

10a. CLASS I	10b. TYPE stranded bare	10c. SIZE 1/2"	10d. MATERIAL copper
10e. BEND RADIOUS 10"	10f. SECURELY ANCHORED [X] YES [ ] NO	10g. PROPER FITTINGS [X] YES [ ] NO	10h. LOCATED AND SPACED AS SPECIFIED [X] YES [ ] NO

10i. PROPERLY BONDED TO ROOF CONDUCTORS/AIR TERMINALS AND GROUNDING ELECTRODES: [X] YES [ ] NO

10j. DEFICIENCIES: nonee

11. GUARDS

11a. TYPE PVC	11b. PROPER FITTINGS [X] YES [ ] NO	11c. SOLIDLY ANCHORED [X] YES [ ] NO

12. GROUNDING ELECTRODES

12a. TYPE copper clad	12b. SIZE 5/8"	12c. LENGTH *(Each)* 20 ft	12d. FORM COUNTERPOISE LOOP [X] YES [ ] NO
12e. DISTANCE BELOW GRADE LEVEL 2 ft	12f. DISTANCE FROM OUTER WALL 6 ft		12g. PROPERLY INSTALLED [X] YES [ ] NO

12h. PROPERLY CONNECTED TO OTHER GROUNDING SYSTEMS OF THE BUILDING: [X] YES [ ] NO

12i. PROPERLY CONNECTED TO DOWN CONDUCTORS: [X] YES [ ] NO

12j. GROUND RESISTANCE MEASUREMENT: 10 ohms

DA FORM 7452-2-R, FEB 2002 USAPA V1.00

Figure 3-31. Sample of completed DA Form 7452-2-R

(6) Verify that the down conductors are routed properly. Verify fasteners and hardware are accessible and are the proper type and material.

(7) Verify that adequate guards are provided where necessary.

(8) Maintain a copy of all drawings, initial site surveys, checklists, and data collected during construction in the facility records department. Prepare test reports, certified by the testing organization, of ground resistance at each test location. Include observations of weather and other phenomena that may affect test results. Describe measures taken to improve test results.

3-5. Signal reference subsystem

Signal circuits are grounded and referenced to ground to establish signal return paths between a source and a load, control static charge, or provide fault protection. The desired goal is to accomplish each of these three grounding functions in a manner that minimizes interference and noise. If a truly zero impedance ground reference plane or bus could be realized, it could be utilized as the return path for all currents -- power, control, audio and RF -- present within a system or complex. This ground reference would simultaneously provide the necessary fault protection, static discharge, and signal returns. The closest approximation to this ideal ground would be an extremely large sheet of a good conductor such as copper, aluminum, or silver underlying the entire facility with large risers extending up to individual equipment. The impedance of this network at the frequency of the signal being referenced is a function of conductor length, resistance, inductance, and capacitance. When designing a ground system in which RF must be considered, transmission line theory must be utilized.

a. Isolation from fault protection subsystem. Because of the interference threat that stray power currents present to audio, digital, and control circuits (or others whose operating band extends down to 60 Hz or below), steps must be taken to isolate these large currents from signal return paths. Obviously, one way of lessening the effects of large power currents is to configure the signal ground system so that the signal return path does not share a path common with a power return.

(1) The first step in the development of an interference-free signal reference subsystem for an equipment or a facility is to assure that the ac primary power neutral or grounded conductor are interconnected with the safety grounding network at only one point. Isolation of ac power returns from the signal reference subsystem is a major factor toward reducing many noise problems. Additional steps should also be taken to minimize other stray ac currents such as those resulting from power line filters. One way of reducing these currents is to limit the number of filter capacitors in an installation by using common filtered ac lines wherever possible or by locating the filters as near as possible to the power service entry of the facility.

(2) To meet the safety requirements while minimizing the effects of power currents flowing with signal currents through a common impedance, a single connection between the power distribution neutral and the earth electrode subsystem is necessary. This single connection eliminates conductive loops in which circulating (power) currents can flow to produce interference between elements of the signal reference network. This connection to the earth electrode subsystem should be made from the first service disconnect. Care should be taken to ensure that the signal reference, fault protection, and lightning protection subsystems are bonded to the earth electrode subsystem at separate ground rod locations.

b. Typical configuration. Within a piece of equipment the signal reference subsystem may be a sheet of metal which serves as a signal reference plane for some or all of the circuits in that equipment. Between equipment, where units are distributed throughout the facility, the signal ground network usually consists of a number of interconnected wires, bars, or a grid that serves an equipotential plane. Whether serving a collection of circuits within equipment or serving several pieces of equipment within a facility, the signal reference subsystem will be a floating ground, a single-point ground, a multiple-point ground, or an equipotential plane. Of the aforementioned signal reference subsystems, the equipotential plane is the optimum ground for communications-electronics facilities.

(1) A floating ground is illustrated in figure 3-32. In a facility, this type of signal ground system is electrically isolated from the building ground and other conductive objects. Hence, noise currents present in the building's ground system will not be conductively coupled to the signal circuits. The floating ground system concept is also employed in equipment design to isolate the signal returns from the

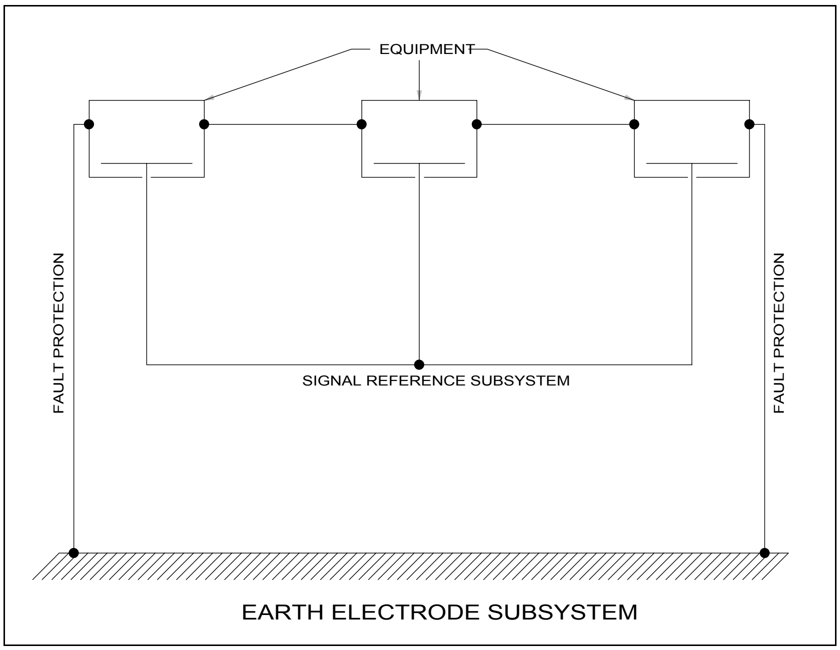

Figure 3-32. Floating signal ground

equipment cabinets and thus prevent noise currents in the cabinets from coupling directly to the signal circuits. The effectiveness of floating ground systems depends on their true isolation from other nearby conductors, i.e., to be effective, floating ground systems must really float. In large facilities, it is often difficult to achieve a completely floating system, and even if complete isolation is achieved it is difficult to maintain such a system. In addition, a floating ground system suffers from other limitations. For example, static charge buildup on the isolated signal circuits is likely and may present a shock and a spark hazard. In particular, if the floated system is located near high voltage power lines, static buildup is very likely. Further, in most modern electronic facilities, all external sources of energy such as commercial power sources are referenced to earth grounds. Thus, a danger with the floating system is that power faults to the signal system would cause the entire system to rise to hazardous voltage levels relative to other conductive objects in the facility. Another danger is the threat of flashover between the structure or cabinet and the signal system in the event of a lightning stroke to the facility. Not being conductively coupled together, the structure could be elevated to a voltage high enough relative to the signal ground to cause insulation breakdown and arcing. This system generally is not recommended for C-E facilities.

(2) A second configuration for the signal ground network (for lower frequencies, 0-30 kHz up to 300 kHz) is the single-point approach illustrated in figure 3-33. With this configuration, the signal circuits are referenced to a single point, and this single point is then connected to the facility ground. The ideal single-point signal ground network is one in which separate ground conductors extend from one point on the facility ground to the return side of each of the numerous circuits located throughout a facility. This type of ground network requires an extremely large number of conductors and is not generally economically feasible. In lieu of the ideal, various degrees of approximation to single-point grounding are employed.

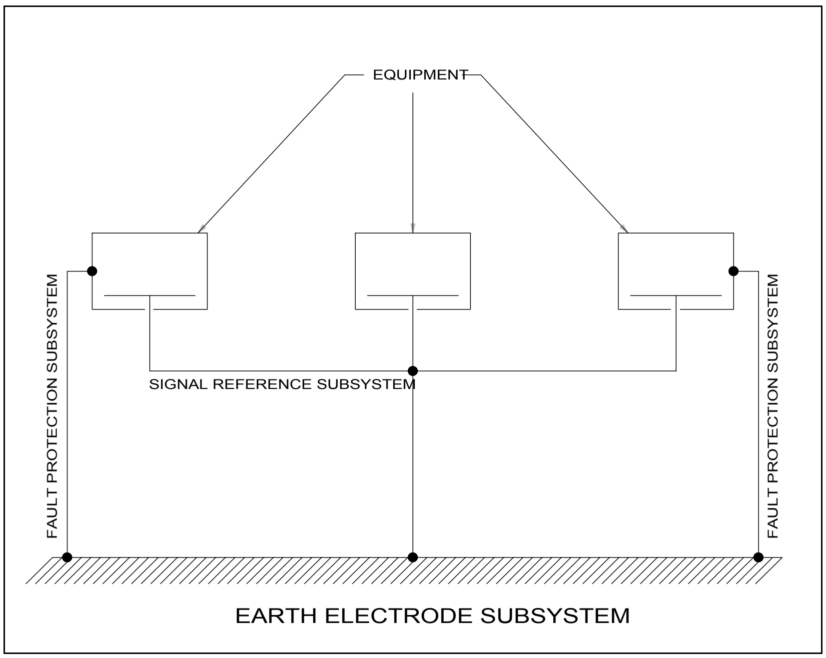

Figure 3-33. Single-point signal ground

(a) The configuration illustrated by figure 3-34 closely approximates an ideal single-point ground. It uses individual ground buses extending from an earth electrode subsystem to each separate electronic system. In each system, the various electronic subsystems are individually connected at only one point to this ground bus.

(b) Another frequently used approximation to the ideal is illustrated in figure 3-35. Here the ground bus network assumes the form of a tree. Within each system, each subsystem is single-point grounded. Each of the system ground points is then connected to a tree ground bus with a single insulated conductor (usually yellow).

(c) The single-point establishes a signal reference plane in each unit or piece of equipment, and these individual reference planes are connected together and to the earth electrode subsystem. An important advantage of the single-point configuration is that it helps control conductively-coupled interference. As illustrated in figure 3-36, closed paths for noise currents in the signal ground network are avoided by the single point signal reference subsystem. The interference voltage, V_N in figure 3-36, in the facility ground system is not conductively coupled into the signal circuits via the signal reference

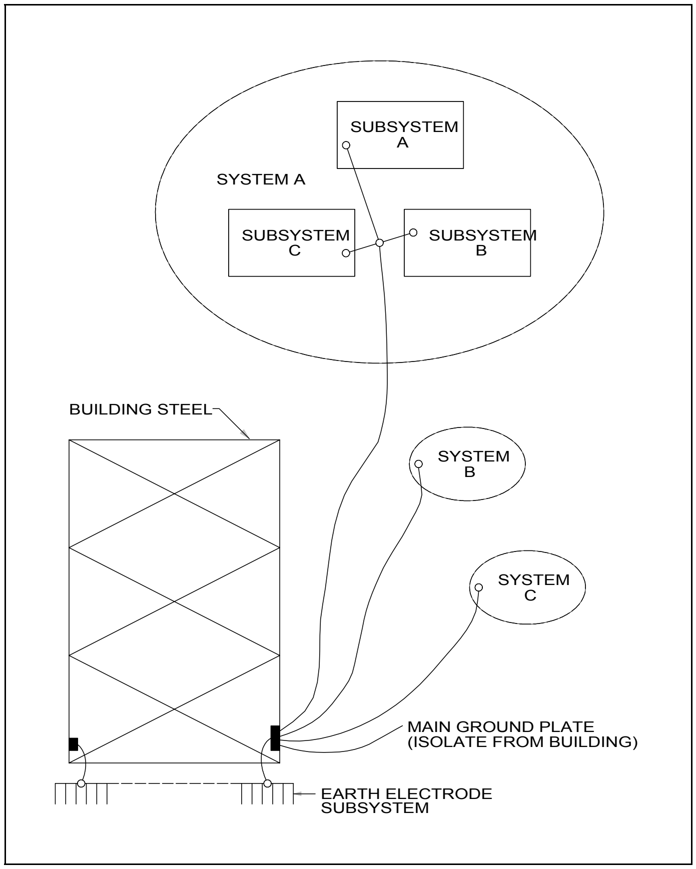

Figure 3-34. Single-point ground bus system using separate risers

subsystem. Therefore, the single-point signal reference subsystem minimizes the effects of lower frequency noise currents, which may be flowing in the facility ground.

(d) Single-point grounds, however, also become transmission lines at higher frequencies with earth being the other side of the line. In addition, every piece of equipment bonded to this transmission line will act as a tuned stub. In the presence of digital signals (square waves) the tuned circuits will ring at the specific frequencies to which they are resonant. Since single-point grounds behave as transmission lines at RF frequencies, they will have different impedances as a function of frequency, i.e., they may appear as inductors, capacitors, tuned circuits, insulators, or pure resistance, and therefore become extremely poor grounds. In a large installation, another major disadvantage of the single-point ground configuration is the requirement for long conductors. The long conductors prevent the realization of a satisfactory reference for higher frequencies because of large self-impedances. Further, because of stray capacitance between conductors, single-point grounding essentially ceases to exist as the signal frequency is increased.

(e) Because of the above conditions, single-point grounds are not recommended for use in communications electronics facilities.

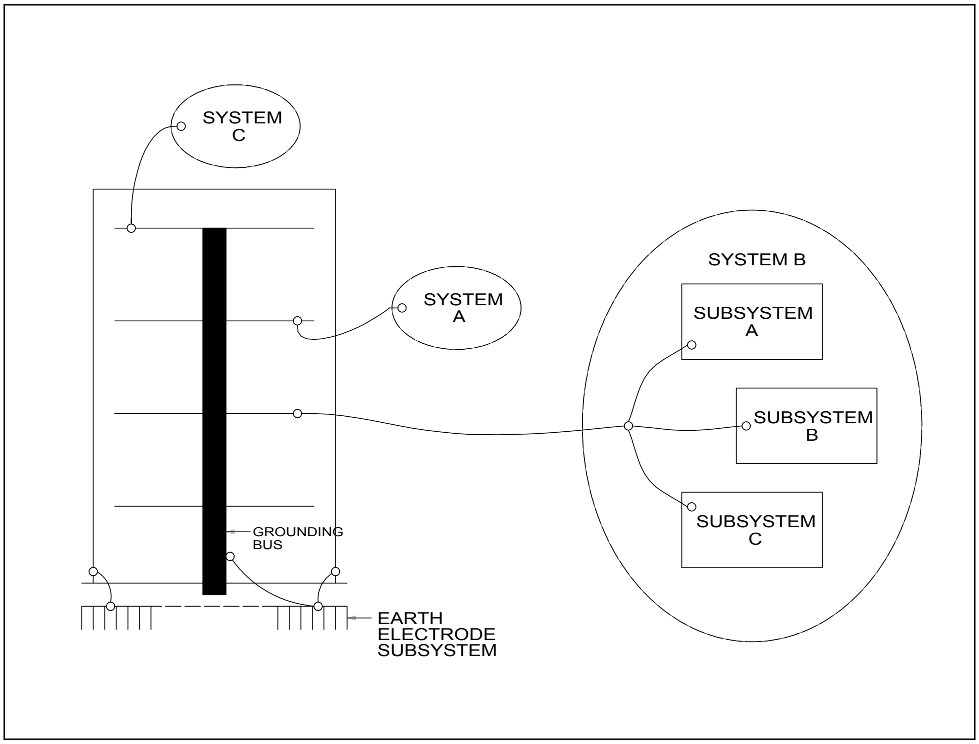

Figure 3-35. Single point ground bus system using a common bus

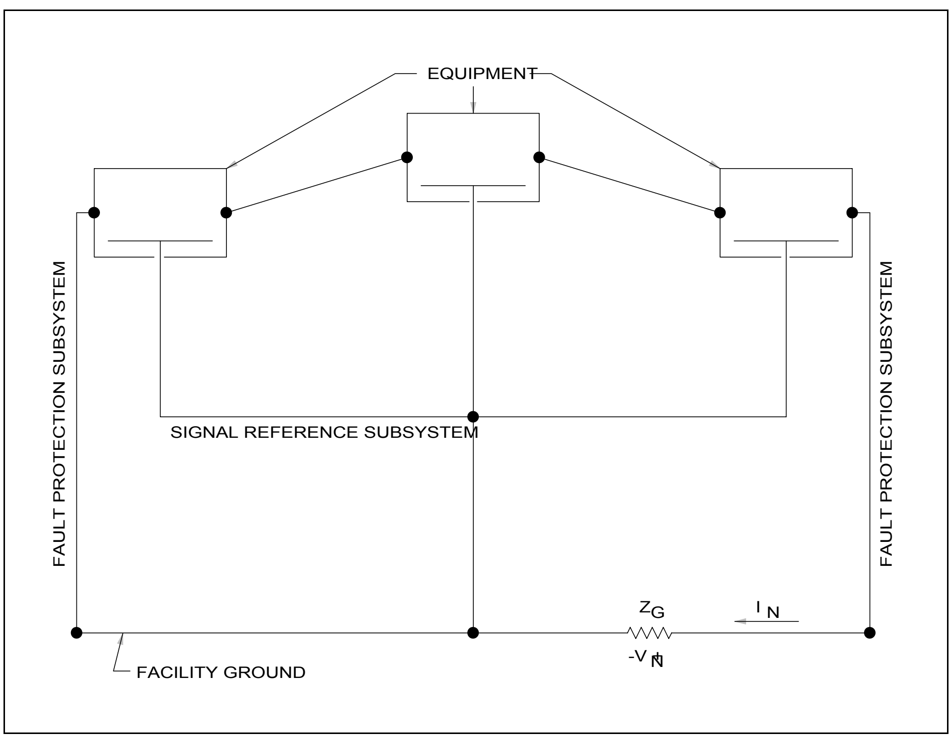

Figure 3-36. Use of single-point ground configuration to minimize effect of facility ground currents

(3) The multipoint ground (for higher frequencies, 30-300 kHz and above) utilizes many conductive paths from the earth electrode subsystem to various electronic systems or subsystems in the facility. Within each subsystem, circuits and networks are connected to this ground network. Thus in a facility numerous parallel paths exist between any two points in the ground network.

(a) Multipoint grounding frequently simplifies circuit construction inside complex equipment. It is the only realistic method for the grounding of higher frequency signal circuits. This method of grounding permits equipment employing coaxial cables to be more easily interfaced since the outer conductor of the coaxial cable does not have to float relative to the equipment cabinet or enclosure.

(b) The multipoint grounding has the disadvantage of exhibiting transmission line characteristics at radio frequencies. Care must also be taken to ensure 60 hertz power currents and other high amplitude lower frequency currents flowing through the facility ground system do not conductively couple into signal circuits and create intolerable interference in susceptible lower frequency circuits.

(4) An equipotential ground plane implies a mass, or masses of conducting material which, when bonded together, offers a negligible impedance to current flow. Connections between conducting materials which offer a significant impedance to current flow can place an equipotential plane at a high potential with respect to earth. The importance of equipotential ground planes cannot be overemphasized for proper equipment operation, as well as for EMI and noise/static suppression. High impedance interconnections between metallic members subject to large amounts of current due to power system faults can be extremely hazardous to personnel and equipment.

(a) The radio frequency interference (RFI) effect of an equipotential plane or system must however be carefully considered, and it is important to understand that grounding may not, in and of itself, reduce all types of RFI. On the contrary, grounding a system may in some instances increase interference by providing conductive coupling paths or radiative or inductive loops. Many of the deficiencies of the wire distribution system can be overcome by embedding a large conducting medium, in the floor under the equipment to be grounded. A large conducting surface presents a much lower characteristic impedance than that of wire because the characteristic impedance is a function of L/C, hence as capacitance to earth increases, impedance decreases. The capacitance of a metallic sheet or grid to earth is much higher than that of wire. If the size of the sheet is increased and allowed to encompass more area, the capacitance increases. Also, the unit length inductance decreases with width, which further decreases impedance. If the dimensions of a metallic sheet increase extensively (as in the case of conducting floor), the characteristic impedance approaches a very low value. In this case, the characteristic impedance would be quite low throughout a large portion of the spectrum. This, in turn, would establish an equipotential reference plane for all equipment bonded to it.

(b) Grounding buses in a communication facility where higher frequencies are present act as lossy transmission lines and therefore must be treated as such. Due to this phenomena, single-point grounds and multipoint grounds employing ground buses are high impedance grounds at higher frequencies. To be effective at the higher frequencies, the multipoint ground system requires the existence of an equipotential ground plane. Equipotential planes are sometimes considered to exist in a building with a metal floor or ceiling grid electrically bonded together, or in a building with the ground grid embedded in a concrete floor connected to the structural steel and the facility ground system. Equipment cabinets are then connected to the equipotential plane. Chassis are connected to the equipment cabinets and all components, signal return leads, etc., are connected to the chassis. The equipotential plane is then terminated to the earth electrode subsystem and to the main structural steel via multiple connections, to assure personnel safety and a low impedance path for all frequencies and signals.

It is again emphasized, however, that care must be taken not to create loops that can couple signals from one system to another.

c. Design considerations. The design of an effective signal reference subsystem depends upon properly identifying the range of signal frequencies likely to be encountered.

(1) A higher frequency grounding network is defined as one that is > 300 kHz, and in some cases down to 30 kHz. The higher frequency (equipotential) grounding network provides an equal potential plane with the minimum impedance between the associated electronic components, racks, frames, etc. This plane shall be used at facilities or areas within facilities where interface frequencies are over 300 kHz and may be used at sites where interface frequencies are as low as 30 kHz. In higher frequency systems, equipment chassis are frequently used as the signal reference. The chassis in turn is usually connected to the equipment case at a large number of points to achieve a low impedance path at the frequencies of interest.

(a) The higher frequency grounding network is a conductive sheet, grid, or cable network mesh providing multiple low resistance paths between any two points within the structure and between any point in the structure and the earth electrode subsystem. It consists of three primary components - equipotential plane, equipment ground conductors, and structural steel elements and electrical supporting structures, connected to the earth electrode subsystem. The equipment grounding conductor (green wire) sha1l not be considered a substitute for this subsystem. The optimum interconnecting cable and mesh spacing of the equipotential plane should be 1/8 of a wavelength with regard to the highest frequency of concern. In practice this may not be feasible and the interconnecting cable and mesh spacing should therefore be as short and small as practical.

$$\lambda = c/f$$

where c = velocity of light in free space = 3×10^8 meters/second
f = frequency in hertz (cycles/second)

(b) The NEC requires that equipment cases and housings be grounded to protect personnel from hazardous voltages in the event of an electrical fault. Stray currents in the fault protection network can present an interference threat to any signal system whose operating range extends down into the lower frequency range and should be eliminated. Where such problems exist, it is advisable to attempt to reduce the impedance of the reference plane as much as possible. A practical approach is to interconnect equipment enclosures with the equipotential plane, via building structural steel, cable trays, conduit, heating ducts, piping, etc., into the earth electrode subsystem to form as many parallel paths as possible. It should be recognized that because of the inductance and capacitance of the network conductors, such multipoint ground systems offer a low impedance only to the lower frequency noise currents; however, these currents can be the most troublesome in many facilities. Higher frequencies find a much lower impedance to ground through the distributed capacity of the equipotential plane.

(c) In steel frame buildings, make all structural members of the building (e.g., building columns, wall frames, roof trusses, etc.) electrically continuous by bonding each joint and interconnection with a welded, brazed, soldered, or high–compression bolted connection. Where direct bonds of these types are not possible, bridge the joint with a l/0 AWG stranded copper cable both ends of which are brazed, welded, or bolted in place. This does not include rebars.

(d) Connect the bonded structural steel network to the earth electrode subsystem with 1/0 AWG copper cables. The distance between adjacent connections from the building structure to the earth electrode subsystem should not exceed 15 meters (50 feet).

(e) Where steel frame construction is not used, install a supplemental network consisting of large copper cables conforming to table 3-7.

(f) Equipment cabinets, electrical supporting structures, and utility pipes are to be connected to this structural steel or copper cable grid (equipotential plane) with #6 AWG copper wire. This interconnecting wire should be as short as feasible, preferably not over 24 inches to minimize high frequency reactance. (Electrical supporting structures include all the conduit, raceways, switch and breaker panels, and other hardware (not energized) commonly associated with the communication electronic facility.)

Table 3-7. Size of equipment ground cables

Cable Size (AWG)	**Maximum Path Length** (FT)
750 kcmil[1]	375
600 kcmil	300
500 kcmil	250
350 kcmil	175
300 kcmil	150
250 kcmil	125
4/0	105
3/0	84
2/0	66
1/0	53
1	41
2	33
4	21
6	13
8	8
Busbar	
4 x ¼	636
4 x 1/8	318
3 x ¼	476
3 x 1/8	238
2 x ¼	318
2 x 1/8	159
2 x 1/16	79
1 x ¼	159
1 x 1/8	79
1 x 1/16	39

[1] kcmil – One thousand circular mils. A circular mill is a unit of area equal to the area of a circle whose diameter is one mil (1 mil = 0.001-6 inch).

(g) The dividing line between the lower and higher frequency should be high enough to include all audio communications signals. Since digital systems employ frequencies, which extend from dc up to several hundred MHz, a decision based on pulsed-signal considerations is more appropriate. To minimize the possibility that the ground bus conductors will form antennas; the lengths should not exceed 0.02 wavelength which is approximately 21 meters (70 feet) at 300 kHz. Since the grounding buses in medium to large sized facilities may extend 21 meters (70 feet), 300 kHz appears to be the maximum frequency for which a single-point grounding system should be used. At frequencies up to 30 kHz, conductor lengths up to 210 meters (700 feet) can be approached without exceeding the 0.02 wavelength criteria. MIL-STD-188-124B establishes the lower frequency network range from dc to 30 kHz and in some cases (depending on the interface frequency) up to 300 kHz. The higher frequency network range extends above 300 kHz and may in some cases be used at sites where the interface frequencies are as low as 30 kHz. The frequency range from 30 kHz to 300 kHz is a mutual area and may be considered as either higher or lower depending upon the interface frequency.

(2) The lower frequency grounding network is defined as the range from 0-30 kHz, and in some cases up to 300 kHz. The lower frequency grounding network for the facility should conform to the following principles:

(a) It should be isolated from other ground networks including structural, safety, lightning and power grounds, etc. The purpose of this isolation is to prevent stray currents (primarily 50/60 Hz power) from developing voltage differentials between points on the ground network.

(b) The inter-equipment or facility ground system should not be expected to provide the primary return path for signal currents from the load to the source. Figure 3-37 illustrates a way of discriminating against those extraneous signals which may inductively or capacitively induce currents into the grounding network and develop differential voltages between the source and the load.

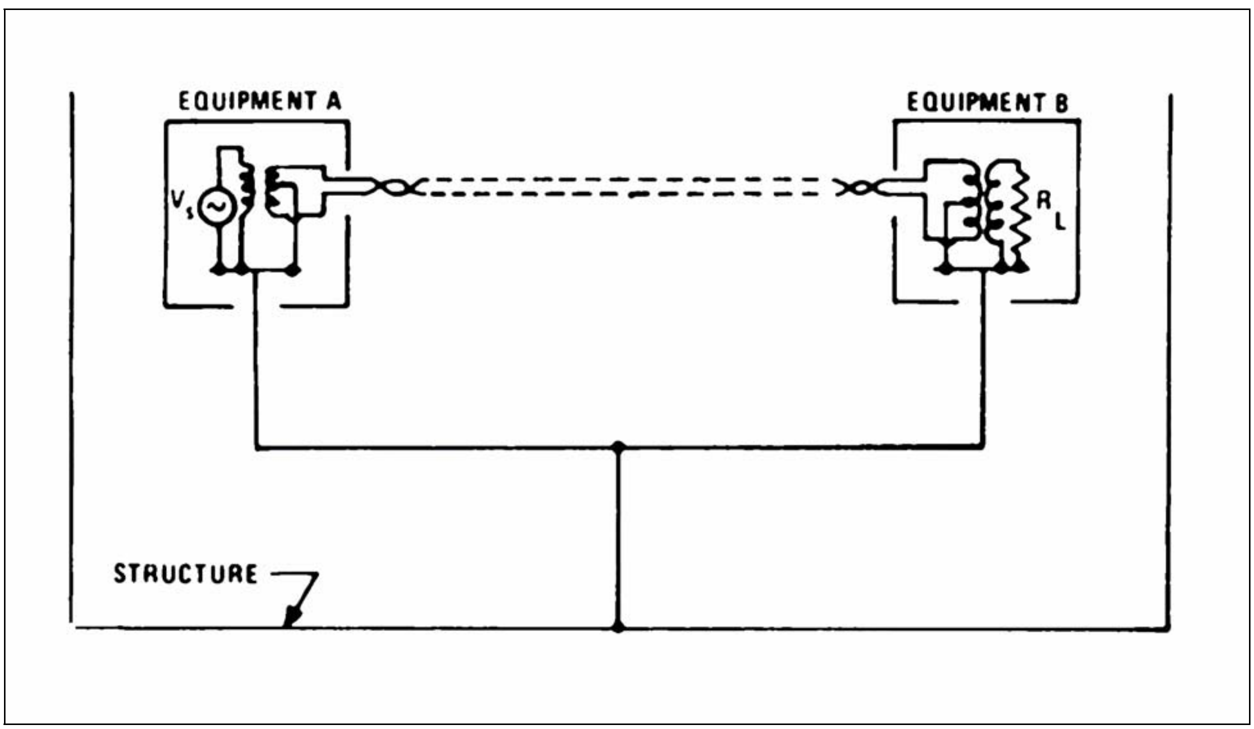

Figure 3-37. Signal coupling for lower frequency equipment

(c) The lower frequency grounding network must be connected to the earth electrode subsystem at only one point.

(d) The network must be configured to minimize conductor path lengths. In facilities where the equipment to be connected to the ground network are widely separated, more than one network should be installed.

(e) Finally, the conductors of the network are to be routed in a manner that avoids long runs parallel to primary power conductors, lightning down conductors, or any other conductor likely to be carrying high amplitude currents.

(f) Lower frequency signal reference subsystems are not recommended as the sole system in communications-electronics facilities.

d. Typical components and installation details. Typical components and installation details for signal reference subsystems are described below.

(1) Conducting media that can be utilized for the equipotential plane generally consists of a copper grid embedded in the concrete floor or raised metal floor such as computer floor. Since a large solid conducting surface is not economically feasible for some installations, a ground reference plane, made up of a copper grid, or copperclad construction mesh with 4-inch openings may be embedded in the concrete with ground risers installed to the surface of the concrete. The mesh is commercially available in AWG wire sizes Nos. 6, 8, 10, and 12. It is normally furnished in 3.7m (12 foot) rolls, but can be obtained in various widths up to 5.5m (18 feet). Where sections of mesh are joined together, there should be a one-foot overlap and bonded together every two feet by welding, brazing, or manufactured connectors that are connected to the grid and give grounding access at the floor surface. Normally, if the grid is embedded in a concrete floor, the latter method provides the easiest grounding source. The equipotential plane shall be welded to the main structural steel of the building at multiple locations. Where frame buildings are utilized, the plane is connected to the earth electrode subsystem at multiple locations using 1/0 AWG copper conductors. If metal floor systems are used (metal floors with concrete poured over the floor) then the floor system itself can be used as the equipotential plane. In fact, this would be the preferred method of establishing the plane.

(2) Where it is not practicable to install a plane on the floor around the equipment, it is possible to install an overhead equipotential plane in or on the ceiling of the equipment room. This can be accomplished by installing either thin metal sheets or screen either above or on the ceiling. Care must be taken to keep bonding straps from the equipment to the plane as short as possible. Generally phosphor bronze screen is used in this application because it is light, durable, and easy to work. The plane must be connected to the building steel, which in turn is bonded to the earth electrode subsystem. Alternately, a ceiling grid arrangement may be used. The grid openings should not be larger than 1/20 wavelength of the highest frequency of concern up to 4 inches. As a design objective (DO), the grid openings should not be larger than 4 inches.

(3) A surface equipotential plane is one usually installed under floor tile or carpet. An equipotential plane can be realized by installing a metal sheet or roll of aluminum, copper, or phosphor bronze under the floor tile or carpet. This sheet may be either thin gauge solid metal or window screen type material bonded to the floor with mastic and tile or carpet installed on top of it. In existing facilities where equipment is already installed, the plane need not be installed under tile equipment cabinets, but must be bonded to the cabinets on all four sides. The plane shall be bonded to the main structural steel members of the building at multiple locations. The structural steel shall in turn be bonded to the earth

electrode subsystem. Alternatively, a ceiling grid arrangement may be used. The grid openings should not be larger than 1/20 wavelength at the highest frequency of concern up to 4 inches. As a DO, the grid openings should not be larger than four inches.

(*4*) Raised floors are used to structurally support equipment cabinets and provide a space between the original facility floor and raised floor plates for cabling, air plenum or air conditioning ducting, piping, drains, etc. Raised floors provide an esthetic room appearance. Three general types of floor systems manufactured are the drop-in grid, the freestanding (stringerless or pedestal-only) type, and the bolted-grid (stinger) system. Only the bolted-grid or the rigid grid system is acceptable as an equipotential plane.

(a) On a drop-in or removable grid system, the grids or stringers are retained by engaging pins or depressions in the pedestal head. The stringers supply support and when newly installed provide comparatively low resistance contact to the pedestal head. Equipment cabinets resting on the floor panels provide increased contact pressure in certain areas. Severe corrosion and unreliable electrical contact have resulted due to dirt, moisture, and floor cleaning/waxing compounds filtering through crevices. This floor system is also considered unsuitable for a reference plane. Floor panels resting on the pedestals and grids are commonly 24” x 24” although they may be purchased in 30” x 30” dimension.

(b) On a freestanding (pedestal-only or stringerless) system, the pedestal base is glued or “shot” in place to form the basic understructure. The pedestal heads are leveled and the floor panel is installed. The conductivity between distant pedestals is variable and unreliable, making it unsuitable for a ground reference.

(c) Bolted-grid (stringer) or rigid grid system raised floors are similar to the drop-in grid except the grids, when properly installed, are securely bolted or clamped in place. The drop-in panels must be metal or wood with metal plate on both sides with a selected floor covering. They should be no larger than 24" x 24." Although the panels may not make a good low resistance contact with the stringers, the high distributed capacitance makes the floor appear to be an electrically continuous sheet at RF frequencies. The equipment cabinets shall be connected to the floor stringers by bonding straps which must be kept as short as possible. This will provide a low impedance path to earth at the lower frequencies. Materials used for stringers and pedestal heads are steel and aluminum. In general, the grounding aspects of raised flooring have been excellent.

(d) Problem areas that designers and installers should be aware of are inadequate bonded joints between pedestal heads due to oxidized dirty pedestal heads when installed, use of poor bolting hardware (speed nuts, sheet metal screws), or bolting hardware not installed or not properly tightened. Composite bonds between cabinet chassis and the raised floor shall not exceed a specified resistance value, usually 1 milliohm. Typically, a pedestal head to stringer resistance will read about 40 micro-ohms and should not exceed 100 micro-ohms.

(e) Connections from the equipment racks and the earth electrode subsystem to the floor are important. Clamps, if used, should be installed on the upper pedestal assembly to avoid the relatively high resistance between the lower assembly (that has the base) and the upper column. The stringer to pedestal fastener hardware can often be changed to allow bolting a bonding cable terminal directly to the pedestal head. It is feasible to obtain additional grid locking hardware and use it to bolt the bonding cable terminal to the floor grid. Another means of terminating a bonding cable is to drill a hole and bolt it to a non-heavyweight bearing stringer.

(f) In extremely humid environments where corrosion is common, the use of corrosion prevention compounds is recommended. Bolted joints can be covered with a non-corrosive silicone-

rubber compound that will protect the joint for the life of the installation. An ice cube rubbed on the silicone-rubber will smooth it.

(g) Carpeting selected as a floor-covering, should be of a low static or static-free type to prevent possible static discharge or component failure.

(h) To determine degradation of the floor, resistance measurements and method should be documented and available so that repeat measurements can be made if ground reference subsystem problems are suspected or periodic checks for degradation made.

(5) The type of ground riser to be used depends on the type of equipotential plane to be installed and whether the subject building will be new construction, a major modification to an existing building in which new equipment will be installed, or an existing building in which only the ground system will be upgraded while the equipment remains in place.

(6) Each individual unit or piece of equipment should either be bonded to its rack or cabinet, or have its case or chassis bonded to the nearest point on the equipotential plane. Racks and cabinets should also be bonded to the nearest point of the plane.

e. Shielding for EDP protection and signal security. Grounding of equipment, conduit, and frames for safety protection in areas processing national security related information (RED data) is no different than any other facility. Typically a RED and a BLACK signal ground is established by a direct connection totally within a controlled space to an equipotential ground plane and earth electrode subsystem. Cable shields from the RED equipment to the RED side of the crypto are grounded at least at both ends. Cable shields from the BLACK side of the crypto equipment through the BLACK intermediate distribution frame (IDF) to the BLACK equipment are normally grounded at both ends. For unbalanced signaling, signal ground is usually established by a direct connection from an isolated signal ground bus in the RED distribution frame to an equipotential ground plane and in turn to the earth electrode subsystem.

f. Inspections and tests. Inspection and testing of the system should be implemented as integral elements of the facility during the construction of the building or structure. To ensure that the implementation is accomplished in a timely manner, the construction efforts should be carefully monitored from the onset of excavation through completion of the facility. Prior to acceptance of the facility, the installation should be validated as acceptable using DA Form 7452-3-R shown in figure 3-38. The following guidelines are provided to aid in the inspection and checkout of the facility.

(1) Examine the drawings and schematics and visually inspect to see if an isolated single-point signal ground is provided. Provide a brief description of the signal ground network or attach copies of the schematics or drawings.

(2) Verify that the internal signal ground network is terminated to an insulated signal ground terminal as required. If a wire is used, verify that the size conforms to the 500 cmil per foot criteria (or as specified) times the length of the wire connecting the single-point signal ground network to the earth electrode subsystem. Enter the information requested on the inspection form.

(3) Verify that the signal ground is correctly identified with a yellow label or color code.

(4) Inspection requirements for the equipotential plane include the following.

(a) Verify that equipotential planes exist in conformance to paragraph 3-5.d.

SIGNAL GROUND REFERENCE SUBSYSTEM CHECKLIST FOR NEW FACILITIES

For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY *Fort Tank*	2. DATE *(YYYYMMDD)* 20020228
3. LOCATION *Building 358*	4. INSPECTOR *Georg Ohm*

5. SKETCH THE LAYOUT OF THE ACTUAL SIGNAL GROUND REFERENCE SUBSYSTEM *(Or attach the up-to-date engineering drawings)*

See attached drawing 001-50-4, 30 November 2001

6. CHECK ALL SIGNAL GROUND COMPONENTS FOR PROPER SIZES, TYPES AND MATERIAL AS SPECIFIED. RECORD ALL DEFICIENCIES.

LOCATION	DEFICIENCIES
Computer room (#12)	*The grounding plate is 2 ft x 1 ft instead of 2 ft x 3 ft as specified*
Telephone room (#15)	*The battery ground conductor is #6 AWG instead of 500 MCM*

7. CHECK ALL SIGNAL GROUND COMPONENTS FOR PROPER CONNECTION, BONDING, AND CONTINUITY. RECORD ALL DISCREPANCIES.

LOCATION	DEFICIENCIES
Computer room (#12)	*The grounding plate is not bonded to the raised floor*
Telephone room (#15)	*The phone switch rack is not grounded*
Tower antenna #6	*The tower metal structure is not grounded*

8. GROUND RESISTANCE MEASUREMENTS *(Use double balanced dc bridge for all joint connectors)*

TEST POINTS	RESISTANCE MEASUREMENT
Bond between grounding plate and raised floor frame in room #11	*.02 milliohms*
Bond between raised floor frame and computer server frame	*.03 milliohms*

DA FORM 7452-3-R, FEB 2002 USAPA V1.00

Figure 3-38. Sample of completed DA Form 7452-3-R *(b)* In steel frame buildings, verify that the equipotential plane is bonded to the main structural steel elements. In wooden or masonry buildings inspect to assure that multiple downleads are bonded to the plane. Insure the red and black signal grounds are bonded to the equipotential plane.

(c) Verify that the structural steel elements are bonded at the joints to produce a low resistance (< 1 milliohm) joint. Welded joints conforming are preferred. Mechanically fastened joints should be carefully cleaned, bolts adequately torqued, and proper bond protection supplied. Visually inspect cleaning procedures, perform spot checks torque measurements, and visually verify that paints and sealants are applied as needed. Perform spot check measurements of bond resistance at structural joints using the double balanced bridge technique. Where bond resistances greater than 1 milliohm are encountered, require that bond surfaces be recleaned, bolts retorqued, or supplemental jumpers provided as needed to achieve 1 milliohm.

(d) In non-steel frame or masonry buildings, inspect the installation of the supplemental grounding network. In particular, verify that the grounding cables provide the required 2,000 circular mils per running foot of conductors times the length of the wire connecting the higher frequency equipotential signal ground plan to the earth electrode subsystem.

(e) Verify that the ground risers are bonded to the equipotential plane and that the bond resistance does not exceed 1 milliohm. Inspect to assure that the ground risers are located to provide the shortest possible lengths to the equipotential plane.

(f) Verify that at least two electrical paths exist between the equipotential plane and the earth electrode subsystem. Preferably the plane should be bonded to the building main structural steel (or downleads in wooden buildings) at least every 3 meters (10 feet). Measure the resistance between selected points on the plane and the earth electrode subsystem to verify that the total resistance does not exceed 5 milliohms. If the resistance does exceed 5 milliohms, check all joints for proper bonding and down hauls for proper sizes. See that all deficient conductors are replaced and that all poor bonds are redone.

(5) Inspect all conduit metallic pipes and tubes for continuity and bonding.

(6) Verify that all electrical supporting structures and cable ways are interconnected and bonded.

(7) Inspect the grounding of the electrical distribution system.

(8) With all cables (signal cables, control lines, power cables, etc.) disconnected, measure the resistance between the signal ground terminal and the equipment case with an ohmmeter. The resistance should be greater than one megaohm. Also, measure the resistance between each ac input terminal (ground wire excluded) and the case. A resistance of one megaohm or greater should be measured. Record both readings on the inspection form. If the measured resistance is less than one megaohm, proceed as follows.

(a) First check to see that all cables, lines, cords, etc., are disconnected from the equipment or that the far ends of any such cables are insulated from other equipment and the structure. Disconnect all cables found still connected.

(b) If no connected cables are found or the low resistance reading still exists after disconnecting all cables, visually inspect the mounting of the signal ground terminal to see that it is properly insulated from tile case or cabinet (disassemble, if necessary). Alternately, disconnect the signal ground connection

inside the equipment and then measure the resistance between just the terminal and the case. If the terminal is not insulated from the case or cabinet, it must be redone.

(c) If the preceding two steps fail to identify the reason for the lack of isolation, the equipment schematics and mechanical layout should be analyzed and inspected to locate the compromise in the signal ground isolation. Be particularly alert for sneak paths through components (transformers, switches, relays, etc.), readout devices (meters, lights), physical contact between the case or cabinet and the signal ground, and wiring errors.

(d) Measure the resistance between the green safety wire and the case; the resistance reading should be 0.1 ohm or less. If a higher resistance reading is obtained, inspect the equipment to see if the green wire in the power cord has been connected to the case or cabinet. If the connection is there physically, was the paint removed from the area of attachment? Are screws or nuts fastened securely? If any of these deficiencies exist, they must be corrected before installing or energizing the equipment.

(e) Inspect all cabling and connectors to see that balanced signal lines are used for lower frequency interfacing lines and that cable shields are grounded only at one end. The shields of individual cable pairs must be isolated from each other except at the common ground points. Check overall shields for grounding. Record any specifically noted deficiencies on the inspection form.

(f) If the equipment is already installed, verify that the signal ground terminal is connected to the nearest feeder ground plate of the lower frequency signal ground network for the facility. Check the size of the cable to see that it conforms to the 500 cmil per foot or as otherwise specified.

(*9)* Inspection requirements for higher frequency equipment include the following.

(a) Verify that higher frequency reference points and planes are directly grounded to the chassis and the equipment case to the extent permitted by circuit design requirements (and unless specified otherwise).

(b) Check to see that properly matched constant impedance cables are used for interfacing purposes. Verify that all connectors are of a type and design that provides a low impedance path from the signal line shield to the equipment case. Do not permit the use of pigtails for the termination of higher frequency line shields outside the equipment case.

(c) Check connectors for tightness, cleanliness, and for proper mounting. Measure the resistance between the connector shell or body and its mounting surface with a double balanced dc bridge. The resistance should not exceed one milliohm. If the resistance exceeds one milliohm, the mounting surfaces should be recleaned to remove all paint, non-conductive coatings, or dirt and all screws or fasteners should be retightened to achieve a close mechanical fit.

(d) Measure the point-to-point resistance between selected points on the case or cabinet with the double balanced bridge. The maximum resistance between any two points on the case or cabinet should be one milliohm or as specified. If the resistance is greater than one milliohm, check to see that all bonding surfaces are properly cleaned and that all connections are securely fastened. (Larger sized grounding cables may have to be added to reduce the resistance to one milliohm or less.)

(e) Record the results of the inspection on the inspection form.

(10) If the lower and higher frequency signal networks are separate, inspect each in accordance with the preceding respective instructions. If the networks involve both lower and higher frequency signals,

inspect for conformance with the higher frequency requirements. Record the results of the inspection on the inspection form.

(11) Check to see that installed equipment, in addition, have their cases or cabinets grounded to the facility ground system of the facility with a cable providing at least 2000 cmil per running foot or as specified. Record results on the inspection form.

(12) Maintain a copy of all drawings, initial site surveys, checklists, and test data collected during construction in the facility records department.